B34

PRICE TEN SHILLINGS AND SIXPENCE

THE JOURNAL OF
The Institution of Electrical Engineers

ORIGINALLY
The Society of Telegraph Engineers
FOUNDED 1871

INCORPORATED BY ROYAL CHARTER 1921

EDITED BY P. F. ROWELL, SECRETARY
SAVOY PLACE, VICTORIA EMBANKMENT, LONDON, W.C.2
Telegrams: "VOLTAMPERE, PHONE, LONDON." Telephone: TEMPLE BAR 7676.

Vol. 84 MARCH, 1939 No. 507

CONTENTS.

The Institution is not, as a body, responsible for the opinions expressed by individual authors or speakers.

PAGE

Thermal Power Plants for Peak-Load and Emergency Service. H. S. HVISTENDAHL, B.Sc.(Eng.) 305

Reviews of Progress:

Power Stations and their Equipment .... Sir LEONARD PEARCE, C.B.E., D.Sc. 342

Telephony and Telegraphy .... W. G. RADLEY, Ph.D.(Eng.) 359

Radio-Telegraphy and Radio-Telephony .... C. E. RICKARD, O.B.E. 368

Broadcasting and Television .... Sir NOEL ASHBRIDGE, B.Sc.(Eng.) 380

The Design and Construction of a Short-Wave Field-Strength Measuring Set. F. M. COLEBROOK, B.Sc., and A. C. GORDON-SMITH 388

Alternating Hysteresis Loss in Electrical Sheet Steels ...F. BRAILSFORD, Wh.Sc., B.Sc.(Eng.) 399

A Note on Standard Calibrations for Sphere-Gaps ....S. WHITEHEAD, M.A., Ph.D. 408

Institution Notes 416

Advertisements.. At end i–xvi

E. and F. N. SPON LIMITED, 57 HAYMARKET, LONDON, S.W.1.
CHEMICAL PUBLISHING COMPANY OF N.Y. INC., 148 LAFAYETTE STREET, NEW YORK.

The Institution of Electrical Engineers.

FOUNDED 1871

INCORPORATED BY ROYAL CHARTER 1921

PATRON: HIS MAJESTY KING GEORGE VI.

COUNCIL, 1938–1939.

President.

A. P. M. FLEMING, C.B.E., D.Eng., M.Sc.

Past-Presidents.

COLONEL R. E. CROMPTON, C.B., F.R.S.
SIR JAMES SWINBURNE, BART., F.R.S.
CHARLES P. SPARKS, C.B.E.
ROGER T. SMITH.
LL. B. ATKINSON.
J. S. HIGHFIELD.
F. GILL, O.B.E.
A. RUSSELL, M.A., D.Sc., LL.D., F.R.S.
W. B. WOODHOUSE.
W. H. ECCLES, D.Sc., F.R.S.
SIR ARCHIBALD PAGE.
LIEUT.-COL. K. EDGCUMBE, T.D.
COLONEL SIR THOMAS F. PURVES, O.B.E.
CLIFFORD C. PATERSON, O.B.E., D.Sc.
J. M. DONALDSON, M.C.
PROF. E. W. MARCHANT, D.Sc.
P. V. HUNTER, C.B.E.
PROF. W. M. THORNTON, O.B.E., D.Sc., D.Eng.
J. M. KENNEDY, O.B.E.
H. T. YOUNG.
SIR GEORGE LEE, O.B.E., M.C.

Vice-Presidents.

SIR NOEL ASHBRIDGE, B.Sc. (Eng.).
J. R. BEARD, M.Sc.
PROF. C. L. FORTESCUE, O.B.E., M.A.
JOHNSTONE WRIGHT.

Honorary Treasurer.

W. McCLELLAND, C.B., O.B.E.

Ordinary Members of Council.

T. E. ALLIBONE, D.Sc., Ph.D.
COL. A. S. ANGWIN, D.S.O., M.C.
L. G. BRAZIER, Ph.D., B.Sc.
T. CARTER.
P. DUNSHEATH, O.B.E., M.A., D.Sc.
C. E. FAIRBURN, M.A.
F. FORREST.
PROF. R. O. KAPP, B.Sc.
E. M. LEE, B.Sc.
E. LEETE.
S. W. MELSOM.

Ordinary Members of Council—(*Continued*).

P. L. RIVIÈRE.
P. J. ROBINSON, M.Eng.
C. RODGERS, O.B.E., B.Sc., B.Eng.
C. D. TAITE.
C. R. WESTLAKE.
G. A. WHIPPLE, M.A.
A. P. YOUNG, O.B.E.

Chairmen and Past-Chairmen of Local Centres.

Argentine Centre:
W. E. TREMAIN.
*C. G. BARKER.

China Centre:
S. FLEMONS.
*C. S. TAYLOR.

Irish Centre:
J. W. O'NEILL.
*LT.-COL. K. E. EDGEWORTH, D.S.O., M.C.

Mersey and North Wales (Liverpool) Centre:
E. L. MORLAND.
*G. K. PATON.

North-Eastern Centre:
F. A. ORCHARD.
*W. D. HORSLEY.

North Midland Centre:
J. W. ATKINSON, I.S.O.
*J. G. CRAVEN.

North-Western Centre:
W. FENNELL.
*J. W. THOMAS, LL.B., B.Sc.Tech.

Scottish Centre:
W. J. COOPER.
*MAJOR H. BELL, O.B.E., T.D.

South Midland Centre:
H. FAULKNER, B.Sc.
*H. HOOPER.

Western Centre:
H. S. ELLIS.
*H. G. WEAVER.

* Past-Chairman.

Chairmen of Sections.

CAPTAIN B. S. COHEN, O.B.E. (*Meter and Instrument*).
S. R. SIVIOUR (*Transmission*).
A. J. GILL, B.Sc.(Eng.) (*Wireless*).

Secretary.

P. F. ROWELL.

Assistant Secretaries.

F. W. HEWITT, M.Sc.; A. E. RAYNER.

LOCAL CENTRES AND SUB-CENTRES.

ARGENTINE CENTRE.

Chairman.—W. E. TREMAIN.
Hon. Secretary.—R. G. PARROTT, Tucuman 117, Buenos Aires.

CHINA CENTRE.

Chairman.—S. FLEMONS.
Hon. Secretary.—W. MILES, c/o Shanghai Telephone Co., P.O. Box 1193, Shanghai, via Siberia.

IRISH CENTRE.

Chairman.—J. W. O'NEILL.
Hon. Secretary.—R. N. EATON, 1, Foster Place, College Green, Dublin.

MERSEY AND NORTH WALES (LIVERPOOL) CENTRE.

Chairman.—E. L. MORLAND.
Hon. Secretary.—W. PARRY, M.Eng., "Scaur," Birkenhead Road, Gt. Meols, Hoylake, Wirral, Cheshire.

NORTH-EASTERN CENTRE.

Chairman.—F. A. ORCHARD.
Hon. Secretary.—L. MELLOR, "Burn Brae," Heworth, Gateshead, Co. Durham.

Tees-Side Sub-Centre.

Chairman.—H. H. MULLENS.
Hon. Secretary.—H. SHAW, "Glenholme," Boosbeck, Saltburn, Yorks.

NORTH MIDLAND CENTRE.

Chairman.—J. W. ATKINSON, I.S.O.
Hon. Secretary.—K. C. COOP, B.Eng., 36, Park Place, Leeds, 1.

Sheffield Sub-Centre.

Chairman.—H. W. KEFFORD.
Hon. Secretary.—A. C. BOSTEL, 23, Stumperlowe Mansions, Fulwood, Sheffield 10.

[*Continued on page (III) of Cover.*

THERMAL POWER PLANTS FOR PEAK-LOAD AND EMERGENCY SERVICE

By H. S. HVISTENDAHL, B.Sc.(Eng.), Associate Member.*

(*Paper first received* 30*th September*, 1937, *and in final form* 29*th August*, 1938; *read before* THE INSTITUTION 10*th November, before the* WESTERN CENTRE 7*th November, before the* NORTH MIDLAND CENTRE 9*th November, and before the* NORTH-EASTERN CENTRE 14*th November*, 1938.)

SUMMARY

The paper discusses first the operating conditions and distinguishes between the different classes of service to be furnished by stand-by plants.

Subsequent sections deal with the choice of fuel, and the fields of application of oil-engine and steam plants. It is shown that only steam plants are suitable for large outputs, to which the greater part of the paper is accordingly devoted, explaining the particular requirements affecting the auxiliary supply, the arrangement of the stations, and the turbine and boiler design, and describing the means and types of equipment which have been evolved to meet those requirements.

Finally, three short sections deal respectively with instantaneous stand-by steam plants, automatic stand-by steam plants, and various recent installations of special interest.

(1) OPERATING REQUIREMENTS AND CLASSIFICATION OF STAND-BY STATIONS

A major interruption of the electric supply in a city of any importance is nowadays attended with such disastrous consequences as to render imperative the provision of some reserve source of power, capable of supplying the requirements of at least the vital services, wherever such failures are liable to occur.

The main causes of supply failures are breakdowns of transmission lines resulting from switching surges, lightning discharges, hurricanes, floods, and earthquakes. Further possible causes of interruption, which, unfortunately, cannot always be disregarded, are strikes, acts of sabotage by malicious persons or rioters, and destruction by enemy bombardment.

Stand-by stations frequently serve a purpose other than merely ensuring the maintenance of the essential services upon failure of the usual power source. They can be employed to assist occasionally the main supply, or even for taking regular peak loads which are beyond the capacity of the generating equipment or of the transmission line. Such plants should therefore be considered with particular reference to the type of service for which they are primarily intended, and to facilitate this task the following classification is proposed: (*a*) Emergency-service plants, for operation upon failure of the usual supply. (*b*) Occasional-service plants, for assisting the usual supply at critical times. (*c*) Regular peak-load plants, operating in accordance with a predetermined schedule.

Although changeable or unforeseen conditions may demand different kinds of service from the same plant, it will usually be possible to identify a proposed installation more or less closely with one or other of the above groups. The operating conditions and characteristics of the three typical classes of station are summarized in Table 1.

Power plants of the first group find application when a district or an important consumer would otherwise be entirely dependent on one or two long transmission lines, or because of the vulnerability of the ordinary supply source. They are seldom in service, but, when called upon for duty, they must be capable of being started up without aid from any external power system and in the shortest possible time. They are necessarily located at, or close to, the load centre.

Table 1

SERVICE CONDITIONS AND CHARACTERISTICS OF THE THREE FUNDAMENTAL CLASSES OF STAND-BY PLANTS

	Emergency service	Occasional service	Regular peak-load
Probable yearly service, hours	0–200	200–500	500–1 500
Probable plant use-factor,† per cent	0–2	2–4	3–8
Maximum admissible starting time, min.	5–10	10–20	10–30
Auxiliary supply at starting	Own	Own and/or external	External
Possible choice of fuels	Oil	Oil and/or gas	Oil and/or gas or pulv. coal
Number of attendants	0–2	2	Depends on load-schedule and fuel

---

* Brown, Boveri and Company, Ltd.

† The plant use-factor here referred to, also called the capacity factor, is defined as the ratio of the actual number of units sent out in a year to that theoretically possible with uninterrupted operation at continuous maximum rating. It is inadvisable to call this quantity the load factor, as this term is employed for another purpose, namely to denote the ratio of the average to the maximum kilowatt demand.

Power plants of the second group comprise those intended for dealing with unusual peak loads, such as may be caused by fogs or storm clouds, as well as for making good temporary deficiencies of generating capacity due to overhauls, or seasonal shortages of water in hydro-electric installations. In the last case, the stand-by plant can be planned as an integral part of the scheme, enabling the hydro-electric station to be built for a greater output than would be justified by the minimum water flow. Quick starting is still required, but need not be as rapid as in the case of the emergency stand-by plant, because a warning service will generally enable the unit to be got under way in time to supply the deficiency. Such stations can, as a rule, depend upon external power for the auxiliaries at the moment of starting.

Regular peak-load plants find a use because they offer a cheaper or more convenient alternative to the extension of a possibly unfavourably located generating station, or to the duplication of a long transmission line, when the growth of the load has caused the peaks to exceed the capacity of the supply source or transmission system.

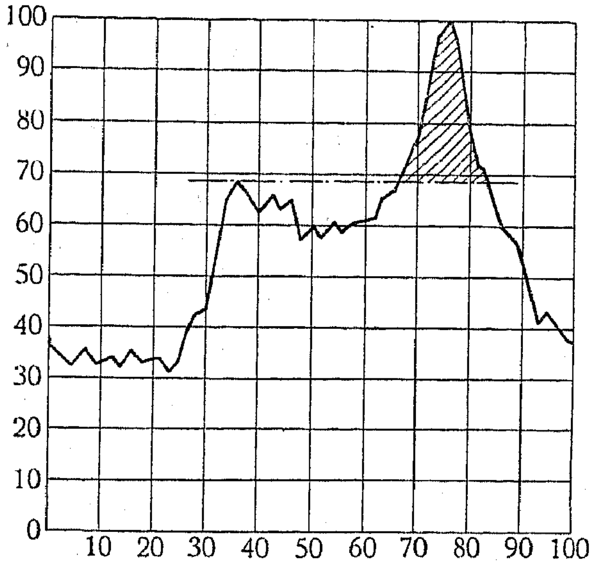


Fig. 1.—Typical winter-day load curve for a large city.

They are also used where energy can be purchased at a low price up to a limited kilowatt demand but a high tariff has to be paid if this limit is exceeded; or, because a combination of base-load and peak-load stations provides the most economical means of dealing with given load conditions. The saving attainable in this last case can best be gauged from a study of the daily and duration load-curves, typical examples of which are reproduced in Figs. 1 and 2. It is clear from the daily curve that additional capacity has to be brought into service for supplying that part of the demand created by the high evening peak, which in the case concerned is due to the winter lighting load, and is present during a few months of the year only. The duration curve, which is derived from the daily load-curves for the whole year by dividing the area enclosed by each such curve into narrow vertical strips, and rearranging all these strips in order of decreasing height, shows that, in the case illustrated, the upper 33 per cent of the kilowatt demand is responsible for less than 2 per cent of the total number of units consumed.

The installation, in the form of an inexpensive peak-load station, of the relatively large fraction of the total generating capacity required for supplying this small percentage of units consumed, not only results in a substantial saving in capital but also greatly improves the load factor of the base-load plant. This last consideration is an important one, because the high efficiencies made possible by the use of high pressures and temperatures, extensive feed heating, and re-superheating where the latter is employed, cannot be maintained unless the load conditions are reasonably steady. The peak-load station is therefore justified in such a case, because the total saving from all causes greatly outweighs the increased fuel costs of the few kilowatt-hours generated by the peak-load equipment.

Plants of this third group operate in accordance with a predetermined schedule, and a longer starting time can accordingly be allowed than in the case of the first two classes; also, here again, external power will generally be available for getting the station under way.

Stations of the emergency-service and occasional-service classes have to be capable of starting up at short notice. Small Diesel plants for such duty can be made entirely automatic in operation, but large Diesel units and steam plants, even if remote-controlled, will require an operating staff to be permanently on the premises. This staff, whose ordinary duties will consist mainly in keeping the equipment in condition for immediate service and trying it out at regular intervals, must, in the interests of economy and freedom from labour difficulties, be kept as small as possible. Automatic starting, paralleling, and load-regulating apparatus, combined with centralization of the controls and measuring instruments, would enable such a station to be manned by a single operator, assisted by occasional visits from an inspection and maintenance crew; but, to allow for unavoidable absence from duty, it is better to employ not less than two men. The case of the regular peak-load plant is different; the number of attendants will depend upon its size and operating schedule, as well as on the kind of fuel burnt.

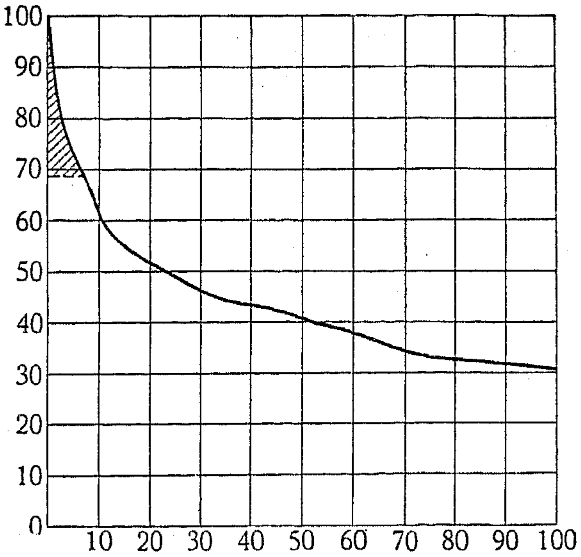


Fig. 2.—Typical duration load curve for a large city.

(2) CHOICE OF FUEL

Economical and, especially, practical reasons render necessary the use of oil fuel for plants of the first group. Although in most countries the price of oil per B.Th.U.

is higher than that of coal, the number of running hours of such stations is so small that the difference is more than offset by the saving of interest and depreciation charges on the coal handling and storage plant and of additional staff wages. On practical grounds, oil is preferred because it affords greater firing flexibility and convenience, cleanliness, freedom from smoke and ash nuisances, and, chiefly, because it makes the operation of the station independent of manual labour. Finally, it should be noted that oil can be stored almost indefinitely without loss or deterioration, and if the tanks are of the underground type and suitably segregated, safety to surrounding property and immunity from wilful damage can be assured.

Gas presents much the same advantages as oil in regard to ease of handling, firing, flexibility, and cleanliness, but it is only in exceptional cases that economic supplies, such as natural gas, refinery gas, and coke-oven or blast-furnace gas, are available in sufficient quantities, whilst ordinary coal gas not only usually compares unfavourably in cost with fuel oil but also has the objection of vulnerability of the gasometers. By-product gas-works tar oil, if available, is just as suitable as ordinary commercial fuel oil, but under normal circumstances the latter is cheaper.

Coal is limited to steam stations and may be seriously considered for plants with a certain minimum number of operating hours, or, more correctly, with a certain minimum plant use-factor.* The critical value of this plant use-factor depends on the relative costs of coal and oil, and on the extra wages and other charges associated with the provision, operation, and maintenance, of coal-handling, storage, and pulverizing equipment and ash-disposal plant. For European conditions the critical plant use-factor is usually between 7 and 10 per cent, equivalent to about 600 to 900 hours' operation per annum at maximum continuous output, or 1 200 to 1 800 hours per annum at an average load of 50 per cent of maximum continuous rating. For oil-producing countries, and ports with facilities for discharging complete tanker loads, the critical value of the plant use-factor may be much higher, oil not infrequently displacing coal in base-load stations. Moreover, it should not be forgotten that coal cannot be stored without waste, the chief causes of which are loss of volatile constituents, scattering by wind and rain, spontaneous combustion, and pilfering.

(3) STAND-BY OIL-ENGINE PLANTS

Diesel-engine generating units have been built with maximum rated outputs up to 15 000 kW,† but their high price per kilowatt installed, which for capacities of this order is half as much again as that of modern oil-burning steam stations, together with the extra costs of lubrication and of higher-grade fuel oils—only partly compensated by their higher thermal efficiency—restricts their economical application to stations of less than 3 000 kW output. This limit is, of course, not sharply defined and depends on individual conditions. It is, however, a very good guide, and hence it may generally be taken for granted that, if the power requirements are substantially above 3 000 kW, a steam plant will provide the more economical solution, whereas if they are substantially less an oil-engine station is indicated. Oil-engine units accordingly find application in emergency stand-by plants for hospitals, radio stations, and industrial or other concerns whose power requirements do not exceed 3 000 kW, and where continuity of supply must be assured at all costs.

Such plants should preferably be self-starting on failure of the normal supply, this being achieved in the case of small engines by means of a motor-car type of self-starter operated from a battery. In the case of medium- and large-size units the electric self-starter becomes complicated and costly, so that it is preferable to resort to compressed-air starting, thereby also avoiding the sudden heavy drain of current on the battery, which has then to supply only the relay devices.

The compressed air may be applied either to one cylinder only, or to all cylinders. In the first case, the engine crankshaft must always be brought by hand into the starting position, this manœuvre having to be repeated if the engine fails to start at the first attempt. In the second case, starting can be effected with the crankshaft in any position, and the attempt repeated if the engine fails to get away immediately. It is, however, necessary, if the engine is of the usual 4-stroke single-acting type, that the number of cylinders be not less than 5 to ensure that there will be always a starting valve open for the admission of the compressed air.

Fig. 3 shows the connection diagram of an automatic starting arrangement developed for large- and medium-size Diesel engines. A sustained interruption of the normal supply causes the voltage-failure relay VR—which is provided with a time-delay, preventing it from responding to momentary fluctuations—to complete the coil circuit of the control relay R, which, in turn, starts up the motor M, driving the auxiliary oil pump AOP and the air valve cam AVC. During the first two-thirds of the cam travel, the oil pressure builds up, flooding the bearings, and causing hydraulically-operated cooling-water and fuel valves to open. During the remaining third of its travel, the cam lifts the compressed-air valve. The engine then starts, and, as it comes up to speed, the contact SG on the speed governor disconnects the automatic starting device, the oil pressure now being maintained by the engine-driven pump.

The contact segment on the cam, which short-circuits the master switch, voltage relay, and speed governor contacts, ensures that, once started, the cam always makes a complete revolution, and therefore that the compressed-air valve never remains open for a longer period than corresponds to the travel of the raised part of the cam. If the engine fails to start at the first attempt, the cam continues to rotate, the cycle being repeated three times. At this point the time-delay relay TR opens the circuit of the starting device and closes that of the light signal " Diesel failed to start." The master switch MS must then be brought to the " off " position before any further attempt can be made to start the unit.

The control is such that, when started, the set continues to run until it is shut down by returning the master switch to the " off " position. This de-energizes the coil of the electromagnet EM, thereby releasing the weight, which instantly closes the fuel control valve of the engine. The stop device acts directly on the control valve and not on the fuel valve in the supply pipe, to avoid the delay caused by the capacity of the pipe and filter system. Protection is afforded against failure of lubricating-oil pressure or cooling water, by means of the oil-pressure relay OPR and the water-circulation relay WCR, in the circuit of the stop-device magnet EM. In addition to the 3-way master switch on the main control board, there is a separate isolating switch IS, mounted near the Diesel engine, for stopping the unit in an emergency, and for putting the automatic starting gear out of service when the set is being inspected or overhauled.

---

* See footnote, page 305.

† R. J. Jensen: "The Third Stage of Development of the Ørsted Power Station, Copenhagen," World Power Conference, Sectional Meeting, Scandinavia, 1933, Report No. 88.

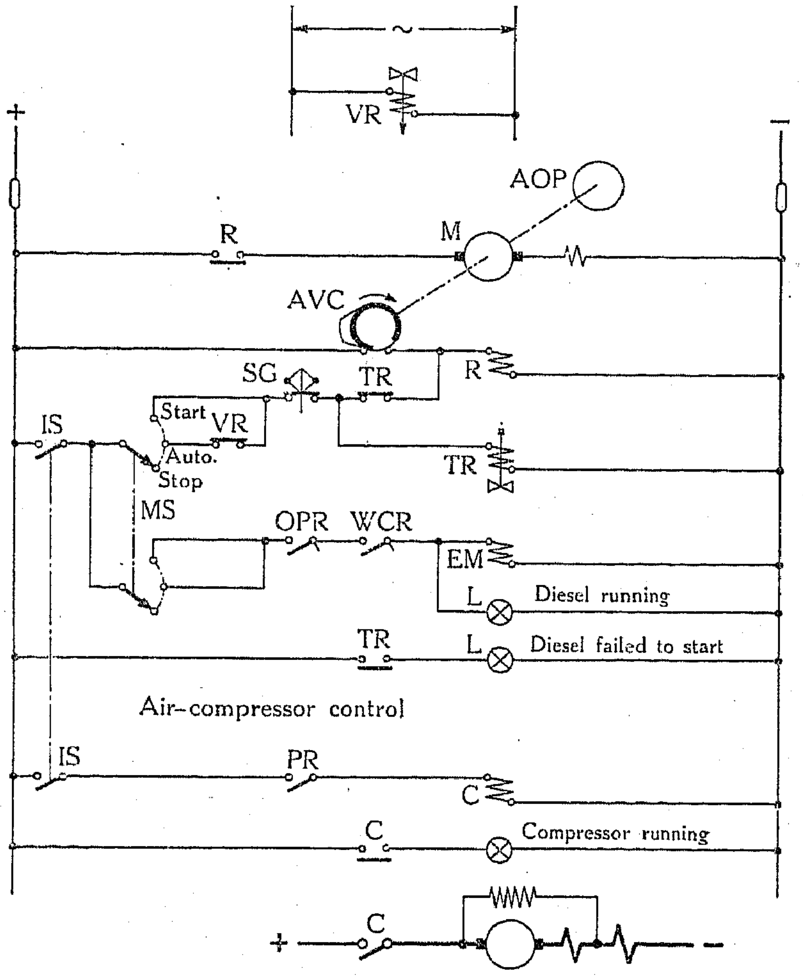


Fig. 3.—Elementary connection diagram of the automatic starting equipment for a large Diesel unit.

AOP = Auxiliary oil pump.
AVC = Air-valve cam.
C = Contactor.
EM = Electromagnet on weight-operated stop lever.
IS = Isolating switch.
L = Signal lamp.
MS = Master switch.
OPR = Oil-pressure relay.
PR = Pressure regulator.
R = Control relay.
SG = Speed governor.
TR = Time-delay relay.
VR = Voltage-failure relay.
WCR = Water-circulation relay.

The compressed-air cylinders are kept charged by a small motor-driven compressor supplied from the usual current source, or preferably from the battery. In special cases, where complete independence of any electrical supply is considered essential, the compressor may be driven by a small, hand-started, oil or petrol engine.

(4) STAND-BY STEAM STATIONS

The size of stand-by plant in which supply authorities are chiefly interested to-day is of the order of 10 000–30 000 kW or over. For such outputs only steam stations can enter into consideration, and it is accordingly with these that the present paper is mainly concerned.

(a) Auxiliary Supply

The first consideration, whatever the class of service, is that of the auxiliary supply at starting. If, as is generally the case for regular peak-load plants, current is available from an external system, an independent source can be dispensed with; but emergency-service stations, and frequently also occasional-service stations, must possess a reliable independent source of energy for getting the station under way. The three possible sources of energy for this purpose are: (i) a battery, (ii) a Diesel set, (iii) a steam accumulator.

The main drawbacks of the first alternative are the size and cost of the battery involved, and the charging losses. This alternative is, nevertheless, an attractive one, as the motor-generator or other reversible convertor which is used for charging the battery may be allowed to run idle, floating on the line. It can then, in an emergency, immediately supply alternating current to the station auxiliaries, the line breaker being tripped out by a reverse-power relay. The auxiliaries are, of course, switched over as soon as possible to the main alternator or to the house set, to relieve the battery.

The second alternative, the Diesel set, is the most common. The unit may be arranged either for hand-starting or, as previously described, for automatic starting. Even so, the time-interval from the moment the master no-volt relay operates until the load can be applied, is of the order of 20–40 sec., which means a corresponding delay in getting the station into service.

In order to reduce as far as possible the demand on either the battery or the Diesel set, various means can be employed to keep down the initial power consumption of the auxiliaries. There is, for instance, no need to circulate the full water quantity through the condenser of the main unit, as the amount of steam to be dealt with during running-up is but of the order of 10 per cent or less of the full-load flow. The water quantity and, therefore, the power requirements, can be reduced, either by running the main circulating pump at reduced speed, or by providing two pumps, one large and one small, and operating only the latter during starting. Many engineers consider it in any case an advantage for big units to be equipped with two circulating pumps; the larger one, designed for about 70 per cent of the maximum water requirements, being sufficient for most operating conditions, and the smaller one, for 30 per cent, being used at starting and to supplement the larger one at high loads. The reduced-speed method appears preferable, however, as it does not involve any complication of the pipework or the operation of change-over valves.

It is not worth while providing additional small condensate pumps and heater drain pumps, as the saving in power would not justify the additional complication, but if the speed of the circulating pumps is regulated by the use of reduced voltage or frequency, then these other pump sets, as well as the boiler fan motors, and possibly the feed-pump set also, may conveniently be connected to the same reduced-voltage or reduced-frequency supply.

There is, of course, at first no pressure in the boiler, and as the house turbine, or even the main unit, can be started when the pressure reaches about 30 per cent of normal, the feed pump need not run initially at full speed. Alternatively, a small feed pump can be used during starting.

The reason for the choice of the reduced-speed method is the fact that the power taken by centrifugal pumps and fans decreases approximately as the cube of the r.p.m. Speed regulation by rotor-resistance control of slip-ring induction motors does not, however, enable the full saving to be realized, owing to the dissipation of energy in the resistor, and regulation must therefore be achieved by the use of d.c. shunt variable-speed motors or d.c. variable-voltage control, or, if alternating current is preferred, by the use of pole-changing motors, variable-speed shunt commutator motors, or variable-frequency control.

Fig. 4 shows the connection diagram of a d.c. variable-voltage system. The starting supply B, to which are connected the constant-speed drives, namely auxiliaries such as ejector water pumps, fuel pumps, etc., which cannot be run at reduced speed, may consist of either a battery or a Diesel-engine-driven d.c. generator. The voltage applied to the motors, which can be run at reduced speed, is lowered by means of a negative booster NB. The scheme has two notable advantages: first, that all the variable-speed drives can be started up simultaneously and smoothly, by gradually raising the applied voltage; and secondly, that the booster set acts as a transformer, thereby reducing the current demand on the battery or Diesel generator approximately in the ratio of the two voltages. When the main or house generator has been run up, the auxiliary load is transferred to it and the battery or Diesel generator disconnected. The slow-running drives can then be brought up to normal speed by gradually reducing the excitation of the negative booster to nothing, whereupon a no-volt relay causes a magnetic or electrically operated switch to cut out, and shut down, the booster set.

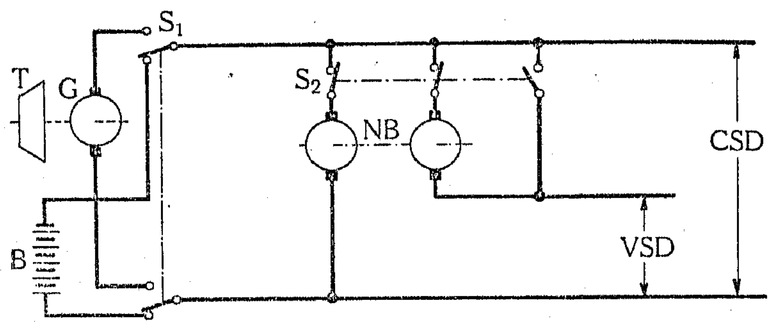


Fig. 4.—Negative booster, d.c. variable-voltage system for reducing the power consumption of the auxiliaries during starting.

B = Starting supply.
CSD = Constant-speed drives.
G = Running supply.
NB = Negative booster set.
S$_1$ = Change-over switch.
S$_2$ = Booster-set cut-out switch.
T = Steam turbine.
VSD = Variable-speed drives.

Fig. 5 shows an a.c. variable-frequency system. Here a Diesel engine drives both the 3-phase alternator A$_1$ and a variable-voltage d.c. generator G. The alternator supplies the constant-speed drives, whereas the variable-voltage generator feeds a d.c. motor M, coupled to the alternator of the house set. By slowly raising the excitation and, therefore, the voltage of the d.c. generator, the house set is gradually accelerated to about half normal speed, and with it the pump and fan drives connected to the alternator A$_2$. The house-set turbine either runs idle, driven by the motor, or is disconnected by an overhauling clutch. When steam becomes available, the turbine starts up, taking over the load, and bringing the set, and hence the drives fed by the generator A$_2$, up to full speed. A reverse-current relay then trips out the switch S$_1$ in the circuit of the d.c. machines, thus preventing the house set from trying to drive the Diesel unit. The constant-speed drives are next transferred by the change-over switch S$_2$ to the house alternator, after which the Diesel set can be shut down.

Unless synchronous motors are employed, the two supplies need not be synchronized before making the transfer; this applies particularly if the operation is effected by a pneumatically or electrically operated switch, as the time-interval is so short that there is practically no drop in speed of the motors and consequently no undue current surge. If synchronous motors are present, which is unusual, they cannot be allowed to fall out of step, and the two supplies must first be paralleled; this operation can, however, be performed by an automatic synchronizer. The breaker of the starting alternator is then tripped out by an auxiliary contact on the paralleling switch.

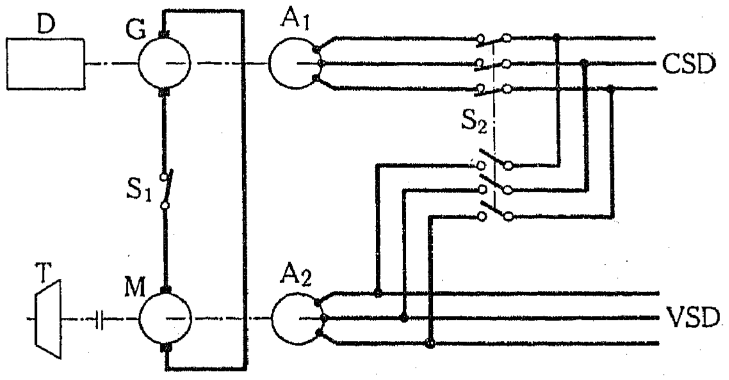


Fig. 5.—Variable-frequency system for reducing the power consumption of the auxiliaries during starting.

A$_1$ = Diesel-driven alternator.
A$_2$ = House-set alternator.
CSD = Constant-speed drives.
D = Diesel engine.
G = Diesel-driven d.c. generator.
M = D.C. motor.
S$_1$ = D.C. reverse-current breaker.
S$_2$ = D.C. change-over switch.
T = Steam turbine.
VSD = Variable-speed drives.

Numerous variations of the two systems described above are, of course, possible, but refinements must never be introduced at the expense of reliability. For this reason it is good policy, particularly in the case of emergency-service stations, not to employ unduly complicated equipment, but rather to install instead a somewhat larger battery or starting set.

The third possible source of energy, namely a steam accumulator, is not advocated as a means of driving the station auxiliaries, although it could be employed for running up a house set with turbine exhausting to atmosphere. The purpose for which it really seems destined, however, is that of shortening the time required for getting the station into service, or even of enabling it to meet without delay a sudden demand for power. Further discussion of this subject is deferred to a later section of the paper.

(b) Choice of Steam Conditions

The cost of fuel for a station with a low plant use-factor being negligible compared with the interest and depreciation charges, it is futile to strive for economy by resorting to high steam pressures and temperatures. The choice of the steam conditions is determined rather by other considerations, namely low capital cost, low maintenance expenses, and, especially, reliability and ability to start quickly. There is no appreciable change in first cost of the equipment up to a pressure of about 400 lb. per sq. in. (gauge), and this value may therefore be taken as the upper pressure limit for emergency-service and occasional-service plants. Above 250 lb. per sq. in. greater care has, however, to be given to the feed-water question, so that it is advisable not to exceed this figure where a plant might have to be operated by an untrained staff, or where circumstances might at any time impose the use of untreated make-up water.

Regular peak-load plants have a better plant use-factor and also generally operate to a definite schedule, so that more attention must be given to maintenance and less importance attached to very quick starting than in the case of emergency-service and occasional-service plants. The nature of their duty, however, introduces a new factor, namely the effect of repeated heating and cooling, tending especially to cause leaky pipe joints. It is accordingly advisable not to increase the recurring transient thermal stresses by the use of unduly high temperatures or pressures, the latter necessarily implying large metal thicknesses. Table 2 gives the steam pressure and temperature conditions which, in the absence of other determining factors, appear best suited to the various classes of plant.

Table 2

SUGGESTED STEAM PRESSURES AND TEMPERATURES FOR DIFFERENT TYPES OF STAND-BY PLANT

	Emergency service plant	Occasional service plant	Regular peak-load plant
Pressure, lb./sq. in. (gauge)	225–400	225–400	300–600
Temperature, °F. ..	600–650	650–750	700–800

(c) Arrangement of Equipment

As already stated, high efficiency is of minor importance compared with the capital cost, and the engineer's task is, accordingly, to select equipment which, whilst satisfying the requirements of reliability, quick starting, and low maintenance charges, will result in the minimum total cost of the complete station, inclusive of land, foundations and buildings, fuel store, and erection. Often the ground space is valuable, or limited by other edifices; in any case the price of the building increases with the size, so that a compact arrangement is always to be aimed at. Where the boilers are oil-fired, the wall between the turbine room and the boiler house can be dispensed with; indeed, certain types of boilers may appropriately be installed in the same bay as, and close to, the turbo-set, with consequent cheapening of pipework, reduction of pipe losses, and simplification of attendance.

In regard to the condensing plant, both the cooling surface and the circulating-water quantity may be chosen somewhat smaller than for a continuous-service station, but it should be borne in mind that the part of the heat drop which is produced at least cost is that in the vacuum region. A poor vacuum means not merely a lower efficiency, but also a higher steam consumption and hence an increase in size, which, although small, applies not only to the boilers but to all components of the feed-water and steam circuits. This extra cost of the boilers and of these components, together with the increased fuel consumption, has therefore to be balanced against the possible saving in condenser surface and on the cooling-water system.

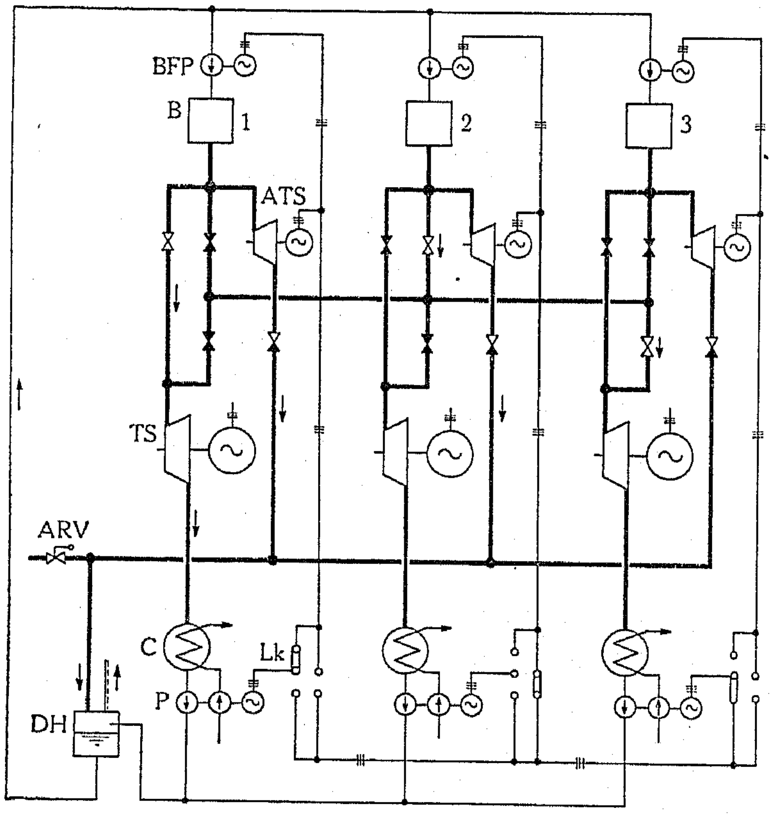


Fig. 6.—Elementary diagram of an emergency-service stand-by plant designed on the unit system.

ARV = Atmospheric relief valve.
ATS = Auxiliary turbo-set.
B = Boiler.
BFP = Boiler feed-pump.
C = Condenser.
DH = De-aerating heater.
Lk = Link.
P = Condenser pumps.
TS = Main turbo-set.

Steam ..	━━━	Valve (open) ..	▷◁
Water ..	───	„ (closed) ..	▶◀
Air ..	═══	„ (non-return)	▷◀ →
Three-phase..	—⫼—		

There is already a noticeable tendency in central-station practice to lay out and to operate as one unit the turbo-set and the boiler or boilers supplying it. This concept is a good one to follow in the planning of stand-by plants comprising two or more sets, especially those of the emergency-service class. Fig. 6 shows the layout of a station designed on this principle. Each main turbo-generator together with a boiler and a turbine-driven auxiliary set—the latter for assuring continuity of supply under all circumstances to the accessory drives—constitutes an independent power unit. Only the condensate return line, which is unlikely to be a source of trouble, is common to all units. To give maximum security, a normally-inoperative interconnecting live steam main is provided. If, owing to an unfortunate combination of circumstances, the boiler of one unit, and the turbo-set of another, should be out of service at the same time, the sound turbo-set can quickly be transferred to the boiler of the defective one.

It is to prevent a shutdown of the auxiliaries and hence of the boiler at such moments, or upon operation of the main turbine overspeed trip, that the auxiliary generator is driven preferably by a separate turbine, instead of by the main one. The auxiliary set should, in fact—especially for plants which are called upon for service precisely at those times when all kinds of external electrical faults are liable to occur—be arranged and operated as part of the boiler.

In Fig. 6, No. 2 boiler is shown connected to No. 3 turbine. The change-over of the condenser auxiliaries is effected by means of a link or similar device, the purpose of which is to ensure against mistakes of the attendant in switch-operating sequence. The same result can, of course, be achieved by interlocked contactors or electrically-operated switches, which, being capable of closing on load, enable the transfer to be effected without stoppage. Synchronization is unnecessary, as a momentary slowing-down of the condenser pumps is of no consequence.

Should it be desired to provide additional security for stations which might have to withstand earthquakes or enemy bombardment, the feed circuits may be kept separate and substantial partitioning walls erected to isolate each complete power unit from the next, and thereby prevent a serious breakdown in one part from causing havoc in the remainder. The main turbo-sets and any high-speed auxiliaries must then be disposed with their shafts parallel to the longitudinal axis of the station, to avoid any possibility of fragments being thrown through the partitions. The wisdom of this precaution is evident when it is recalled that the energy stored at normal speed in the rotor of a 3 000-r.p.m. 30 000-kW turbo-set is of the order of 100 000 000 ft. lb.

(d) Requirements affecting the Turbine Design

Space and first-cost considerations will practically invariably suggest the choice of a single-cylinder 3 000-r.p.m. turbine. Single-cylinder machines running at this speed are now available for outputs up to 50 000 kW, which is the maximum likely to be required of one unit for this type of service. The increased operating economy usually associated with multi-cylinder turbines because of their greater number of stages, is considerably diminished, not only by the low plant use-factor, but also by the moderate steam pressures and temperatures generally prevailing, and vanishes entirely when the increased cost of machine, foundations, and buildings is taken into account.

Radial-flow Ljungström turbines, with their counter-rotating twin rotors, can be run up very quickly indeed. It is, however, important that a fairly high vacuum be first created in the condenser, to ensure that the turbine casing, upon which the alignment of the whole unit depends, remains cool. Notable installations where use is made of the quick-starting characteristics of Ljungström turbines are at the Västerås and Värtan stations in Sweden, and at Homburg in Germany.

The design of axial-flow turbines capable of being run up and put on load quickly, demands special attention. Heavy solid forgings are not necessarily a guarantee of strength and security, as the thermal stresses set up in such forgings during rapid warming-up, when the temperature-rise of the inner portion lags considerably behind that of the periphery, may easily be sufficient to cause a rotor failure at normal running speed. Superfluous metal, far from increasing the margin of safety, lessens it in a two-fold manner: directly, because of the inevitable time-lag between temperature-changes at the surface and in the mass; and indirectly, by reducing the opportunities for contact with the steam.

Reaction as well as impulse-type turbines for quick-starting duty can be designed with proper regard to the above facts, as can be seen from the sectional drawing in Fig. 7 which shows a combined-type machine of 20 000 kW output. The rotor is here built up of a number of forgings welded together at their periphery. The small size of each forging enables the soundness of the metal to be assured; moreover, any stresses which might be set up in or by the welds are relieved by a careful final annealing. The construction allows the shape of each component to be determined solely by the forces it has to withstand. Thus, where the centrifugal force due to the blades becomes appreciable, the forgings take the form of solid discs. The absence of a central bore, necessary in one-piece rotors for inspection purposes, enables the stress to be transmitted diametrically through the centre, instead of tangentially around the hole, thereby doubling the strength of a disc of given section.* Openings, located and dimensioned so as not to weaken the discs, provide for the circulation of a small quantity of steam through the rotor to ensure as nearly as possible a uniform rate of warming-up inside and outside. Another noteworthy feature of this design is the method of mounting the dummy piston and impulse wheel. No keys are employed, the parts being given just sufficient shrink for them to sit firmly on the shaft at normal speed. A welded circumferential joint between two thin, resilient, lip-shaped projections, which take up any differential temperature strains, transmits the torque and eliminates any possibility of the wheels becoming loose. The same general construction is adopted for the larger machine shown in Fig. 16, which differs from that of Fig. 7 only in the provision of a double-flow low-pressure section, to enable increased output to be obtained without increasing the exhaust losses.

(e) Methods of Reducing the Starting Time of Steam Turbines

Whereas in ordinary station practice it is customary to allow from 20 minutes to 1 hour or more for running-up large turbines, machines of the type described above can, in an emergency, be brought from the cold state to full speed in 4–5 minutes for sizes of the order of 15 000 kW, and 6–7 minutes for sizes of the order of 30 000 kW. In cases where this time is still too long, special methods of keeping the turbine warm enable it to be cut down to about 1 and 2 minutes respectively. The alternative of running the set light continuously, which is discussed later, is not really a method of starting.

---

* A. Stodola: "The Steam and Gas Turbine" (Julius Springer, Berlin), 5th ed., p. 321.

The expression " keeping the turbine warm " should be understood to mean " keeping the turbine warm and the shaft straight," because the factors which ordinarily limit the running-up rate of steam turbines are: (i) the maximum rotor stress, as determined by the sum of the centrifugal and transient thermal stresses; (ii) the transient thermal stresses in the casing; (iii) the time required for the shaft to straighten out. In high-pressure turbines, the rate of warming-up of the heavy casing is slower than that of the rotor, but for moderate-pressure machines the contrary holds good, so that for stand-by plants only the first and last factors need be considered. The deformation of the turbine shaft here referred to is not a result of faulty workmanship or material, but is caused by the uneven rate of cooling of the rotor after it has come to rest, and occurs to a greater or lesser extent in every axial-flow turbine.

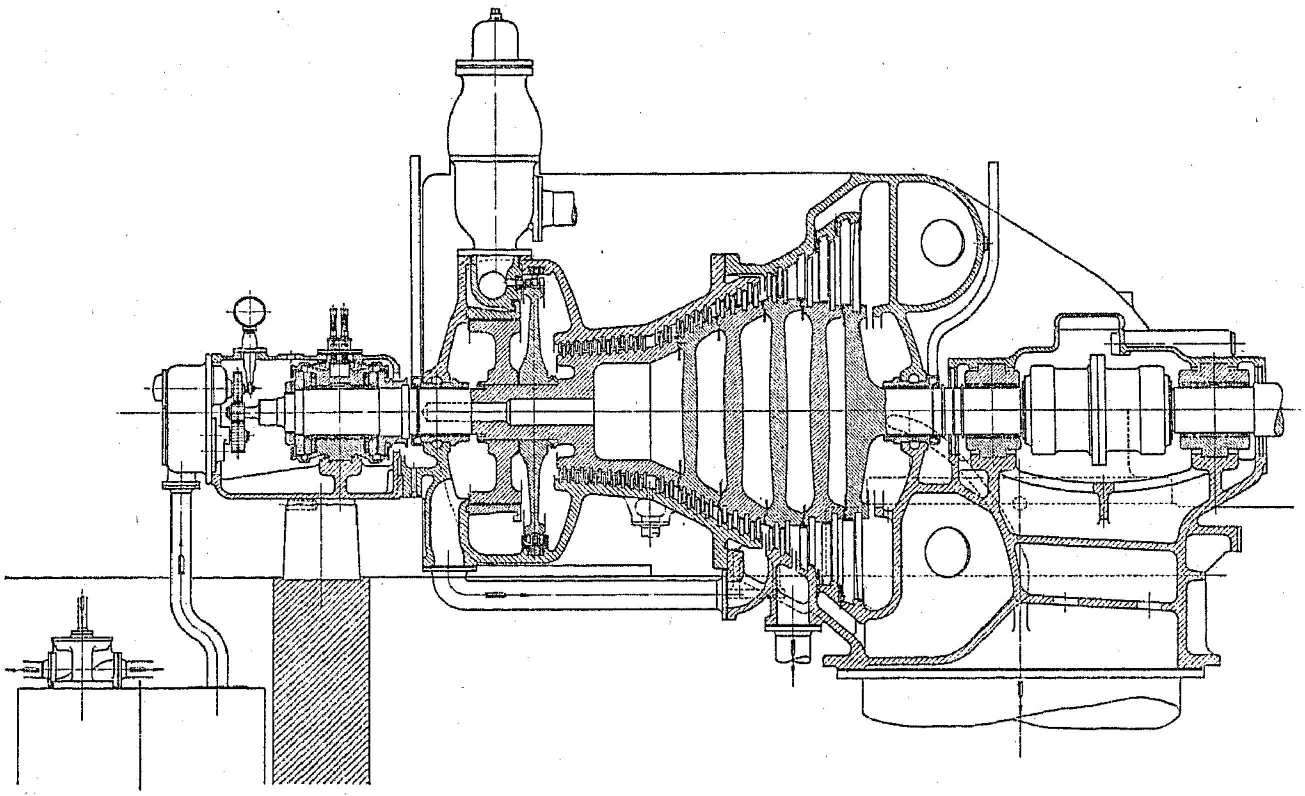


Fig. 7.—Section of a 20 000-kW, 3 000-r.p.m. steam turbine for quick-starting duty.

If this deformation is plotted to a time scale, curves of the form shown in Fig. 8 are obtained. The rising portion corresponds to the temporarily predominating effect of the more intensive cooling at the colder boundaries, and the falling portion to the declining temperature-difference as the rotor cools down. The deformation is not downward, but upward, owing to the heat conducted away at the bearing contact surfaces, and the natural tendency of the hotter vapours to rise to the top of the casing, although the resultant of the deformation and the deflection due to gravity may still be downward. The maximum value is a function of the heat stored in the rotor; that is, the load on the set prior to shutting-down, and is attained after some 3–10 hours. This is evidently the worst possible moment for trying to restart the set quickly, but, even if a very much greater time-interval is allowed to lapse before repeating the attempt, a small residual deformation may still persist, disappearing only under the uniform heating action of the steam when the rotor is again in motion. The initial deflection is, of course, accentuated by the resulting unbalanced centrifugal force; which explains the rapidly-growing vibration sometimes experienced on attempting to run-up a machine faster than is permitted by the rate of decline of the residual deformation.

The obvious method of ensuring that the shaft remains straight after the turbine has been shut down is to rotate it slowly by means of a barring device. This method, however, necessitates a continuously-running high-pressure oil pump, for lifting the rotor by forcing oil under the shaft, as the speed is too low for the establishment of the normal lubricating and cooling oil film.

In addition to keeping the shaft straight, it is necessary to keep the turbine at least moderately warm, both to avoid excessive condensation at starting and to prevent dangerous stresses in, or distortion of, the casing, upon quick application of the load. The need for this precaution is readily appreciated from the fact that very little steam is taken during the running-up period, and, moreover, that the pressure drop is concentrated over the first few stages; whence, if the starting time be short, the greater part of the machine has no chance of warming up before the load is applied. The two main alternative ways of keeping the turbine warm without the use of steam are: (i) the circulation of hot air around the casing,* (ii) the use of electric heating elements embedded in the insulation. The first method requires a fan, which circulates the air in a closed path over a heater and through

* E. Brown: Second World Power Conference, Berlin, 1930, Report No. 328.

passages between the shrouding and the turbine casing. The second method dispenses with both fan and air passages, and appears, therefore, to be preferable to the first. When the turbine is kept warm by either of the above methods, the shaft must not be allowed to remain stationary for fear of distortion, but must be rotated, as upon shutting down, by a barring device. Warming-up by circulation of hot air, combined with intermittent rotation of the rotor, has been applied successfully for a number of years to a 7 500-kW turbine at the Geneva stand-by station.

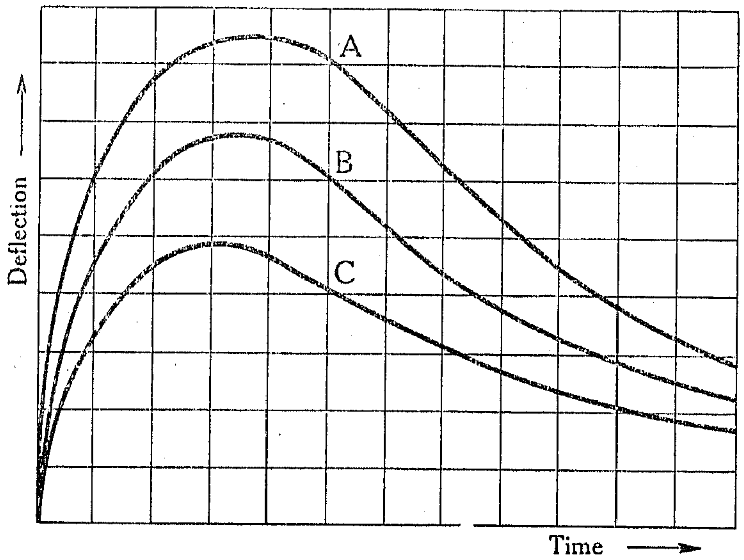


Fig. 8.—Deformation of a steam-turbine shaft after shutting down.

A = After sustained full-load run.
B = After sustained half-load run.
C = After sustained light-load run.

(f) Types of Quick-Steaming Boilers

The practice of keeping up steam pressure by means of a slow fire may perhaps be tolerated on a regular peak-load plant, and where fuel is cheap, but certainly cannot be entertained for emergency-service or occasional-service stations. For these, the only alternative is the installation of some special design of quick-steaming boiler. Oil-firing, together with the provision of a large radiation heating surface, enables the usual time of several hours for bringing an otherwise conventional type of boiler from the cold state to normal pressure, to be cut down to 20–30 minutes; but this is still too long for the classes of duty referred to.

An interesting design of radiation boiler for quick-starting duty, the Forssblad boiler, has been developed in Sweden. According to published figures, the time required to bring an 88 000 lb. per hour unit of this type from cold up to normal pressure was 12 minutes,* normal output being attained after 17 minutes, and maximum output after a further period of 17 minutes. A disadvantage of most radiation types of boiler is the fact that the efficiency is high at low loads only, and falls off appreciably at full load and overload.

Another type of boiler which appears well suited to the quick-starting and other special requirements of stand-by stations is that known as the Velox steam generator. The boiler has been described elsewhere by A. Meyer,† and its operating principle and characteristics are accordingly here recalled only to the extent necessary for the proper understanding of its influence on the design and performance of the station.

The heating surface consists of a layer of water tubes, called evaporator elements, lining the circumference of a closed cylindrical combustion-chamber (Fig. 9). Each element is traversed by a central flue tube, through which the furnace gases, entering at the bottom, escape to the common gas header at the top. A circulating pump draws the boiler water from the bottom of an external vertical drum known as the separator, and forces it, at about 10 times the full-load evaporation rate, up through the evaporator elements to a common header, and thence back into the separator, where the steam separates out by centrifugal action. The saturated steam, leaving the top of the separator, returns to the boiler, where it splits up into a number of parallel streams, to flow through the superheater hairpin elements, located one in the upper part of each evaporator-element flue. The lower portion of each flue contains a short central water tube in parallel with the outer water sleeve.

The air required for the combustion is compressed to about 35 lb. per sq. in. (gauge) by means of an axial-flow compressor. A small part of this pressure head is absorbed in the burner nozzle vanes, to create intensive turbulence in the furnace space, and a further fraction is expended in overcoming the resistance to the high-velocity flow—attaining 600 ft. per sec.—of the gases through the flues of the evaporator elements; but the greater part is absorbed by the gas turbine, which drives the compressor already mentioned. The combustion gases enter this turbine at a temperature of 900° to 1 000° F., thus enabling it to develop all, or more than, the power taken by the compressor. This follows from elementary thermodynamic principles, and can be explained in simple language by the fact that the work available from the expansion between given pressure limits of the larger hot-gas volume is equal to, or greater than, the work of compression between greater pressure limits of the smaller cold-air volume. From the turbine, the gases go to the economizer, and thence to the exhaust duct or stack.

Combustion at 35 lb. per sq. in. (gauge), as may be expected from the law of chemical mass action, is much more rapid than at atmospheric pressure. This, together with the intensive turbulence previously referred to, allows the furnace volume to be cut down to a fraction of that required for conventional boilers, the rate of heat liberation attained being as much as 1 million B.Th.U. per cu. ft. per hour. Moreover, the convection heat-transfer coefficient from the hot gases to the tube wall—being proportional to $(v\rho)^{0\cdot786}$,* where v the velocity, and ρ the density, are respectively 15 and 3·5 times those obtaining in conventional boilers—results in an even greater reduction of the heating surface. This explains why, compared with a modern conventional boiler of the same output, the Velox steam generator has only one-tenth the weight and occupies but one-quarter the space. The light weight and the compactness, as well as the flat efficiency curve referred to later, are no mean

---

* E. Praetorius: "Steam-Raising Tests on Forssblad Boilers," *Archiv für Wärmewirtschaft*, 1933, vol. 14, p. 9.

† "The Velox Steam Generator: a Supercharged Boiler," *Journal of the Institute of Fuel*, 1934, vol. 7, p. 316; also "The Velox Steam Generator: its Possibilities as applied to Land and Sea," *Mechanical Engineering*, 1935, vol. 57, p. 469.

* M. Fishenden and O. A. Saunders: "The Calculation of Heat Transmission" (London, H.M. Stationery Office, 1932), p. 151.

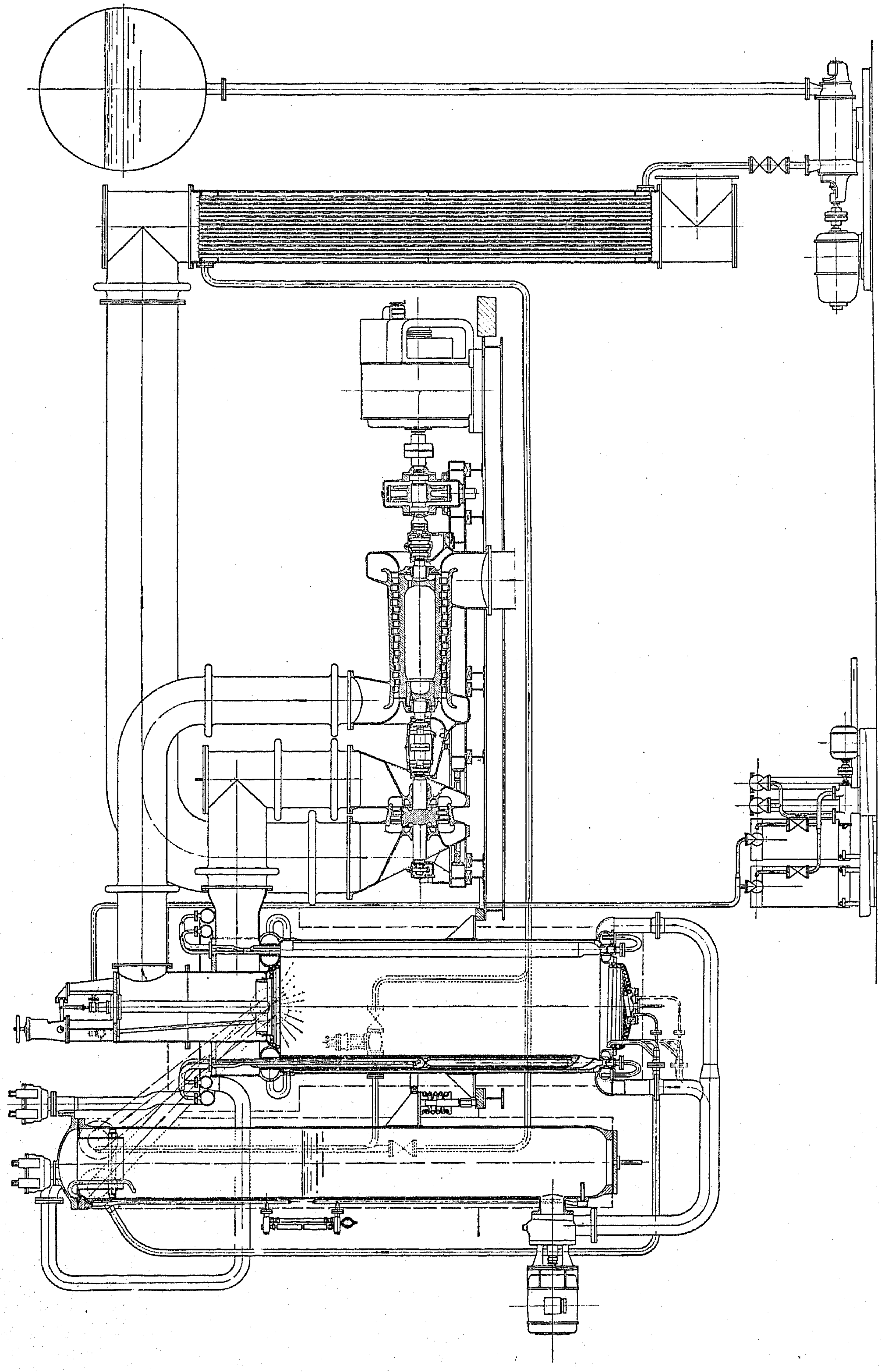


Fig. 9.—Developed section of a Velox boiler of modern design for quick-starting duty.

advantages for this class of duty, but probably the most important advantage is the ability, due to the small water-content and the absence of a refractory furnace lining, to be brought up from the cold state to full-load output at normal pressure within some 3–6 minutes, depending upon the size.

Curves taken during the official works tests on two 100 000 lb. per hour steam generators of this type, for the stand-by plant of the Wellington City Corporation, are reproduced in Fig. 10. Full-load output at normal pressure was reached in less than 4 minutes after starting from the cold state, inclusive of the time taken for running-up the auxiliaries. The somewhat slower rise of the steam temperature, far from being a disadvantage, is very desirable from the point of view of the gradual warming-up of the turbine. The efficiency curve, Fig. 11, characteristic of the boiler type, is remarkable for its flatness, which is due, at small loads, to the low radiation losses, and at high loads to the increase in heat-transfer with supercharging pressure, preventing any appreciable rise of the exhaust-gas temperature.

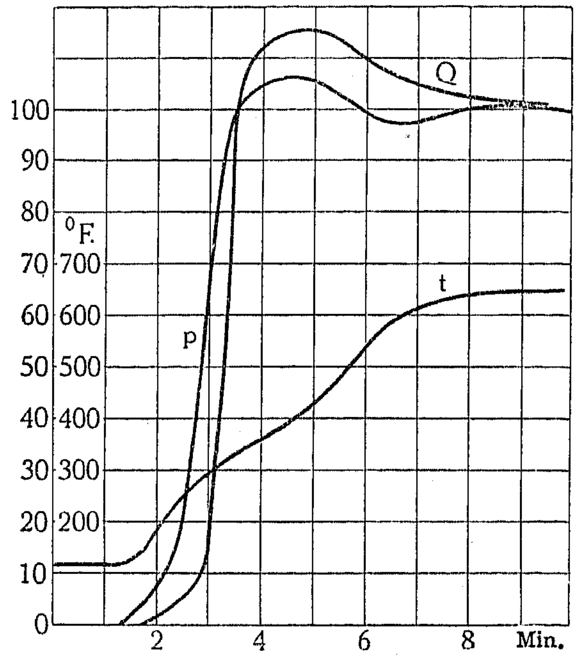


Fig. 10.—Starting curves for a 100 000 lb.-per-hour Velox steam generator.

p = Steam pressure as a percentage of normal.
Q = Steam quantity as a percentage of full load.
t = Temperature, in °F.

The energy for driving the compressor is evidently obtained at the expense of heat abstracted from the products of combustion in their passage through the gas turbine, but, except for the negligibly small bearing and radiation losses, this heat is returned in full to the boiler in the compressed air. It is this all-important fact which makes the supercharged boiler possible, because any attempt to drive the compressor electrically by energy generated on the usual thermal cycle would require an approximately fourfold heat expenditure, of which only one-quarter would be returned to the boiler, the remainder representing an intolerable loss.

The auxiliary electric motor of the supercharging unit, which has a rated output amounting only to some 10 per cent of that of the gas turbine, is merely intended to run the set at reduced speed for starting, and thereafter, by the agency of a suitable control system, to develop momentarily either an accelerating or a retarding torque for regulating the speed of the set, and hence the air quantity, according to the load on the boiler. As soon as the desired speed has been attained, the electrical machine runs light, supplying as a motor, or absorbing as a generator, any remaining small power difference necessary to keep the set running at this speed. The curve N, Fig. 11, shows how this difference passes from a small deficiency at light load to an excess at heavy load, owing to the increasing output of the gas turbine with increasing inlet gas temperature, whereas the temperature of the air drawn in by the compressor remains sensibly constant. Above about half load, not only is no power taken for driving the compressor, but a small excess, generated at practically 100 per cent thermal efficiency—since the heat in the gases leaving the turbine is available for the economizer—is returned to the busbars.

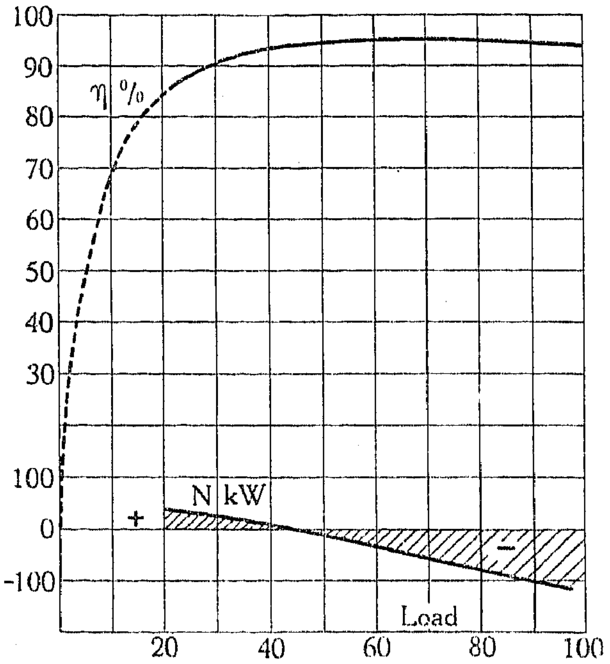


Fig. 11.—Boiler efficiency, and power supplied or absorbed by the auxiliary motor of the supercharging set of a 100 000 lb.-per-hour Velox steam generator.

η = Boiler efficiency.
N = Power difference supplied or absorbed by the auxiliary motor.

(5) INSTANTANEOUS STAND-BY STEAM PLANTS

This name is here used for stations capable of meeting instantaneously a sudden demand for power, even a delay of 5–10 minutes being inadmissible. To fulfil these conditions, the turbine should be kept warm as well as running at normal speed, and some form of accumulator must be provided for supplying it with steam while the demand lasts, or until this function can be taken over by the boiler plant.

A convenient solution to the problem of the continuously-running turbine is to drive it by the alternator, the latter acting as a synchronous condenser for power-factor correction or line-voltage regulation.

To avoid the otherwise impossibly large windage losses, vacuum must be maintained in the turbine, which necessitates running the condenser pumps and supplying sealing steam to the glands. A minute amount of cooling steam must also be allowed to flow through the turbine, because the vacuum is only as low as is permitted by the cooling-water inlet temperature, and hence such windage losses as do occur must not be allowed to cause overheating of the low-pressure end of the machine. The small steam requirements can be supplied either by the accumulator or by a small electric or oil-fired boiler.

In the Ruths system (Fig. 12) the accumulators are charged to a pressure of 150–200 lb. per sq. in. (gauge), and discharge saturated steam to special turbines, provided with a " wandering inlet," and destined to introduce the steam to progressively lower stages as the accumulator pressure decreases. The discharge is continued down to a pressure of 7–10 lb. per sq. in. (gauge). The upper limit of 200 lb. per sq. in. is determined by the cost of the drums and by the maximum moisture-content of the steam in the low-pressure stages. Disadvantages of this system are: the low efficiency, due to the dwindling available heat-drop of the accumulator steam, and also to the unavoidable poor performance of a turbine designed for a widely varying steam pressure; the large space requirements; and especially the high initial cost, which for 1 hour's full-load output attains some 70 per cent of, and for 2 hours' full-load output practically equals that of, a straightforward oil-burning steam station of the same output. Although stand-by and peak-load plants on the Ruths-accumulator system have been installed in several countries—the most notable being those at Malmö, Göteborg, and Stockholm, in Sweden; Hattingen, Oberlungwitz, and Charlottenburg, in Germany; and Amsterdam, in Holland—it is now generally recognized that this system is more suitable for levelling out the peaks and valleys in the varying heating-steam demand of industrial works than for energy-storage purposes.

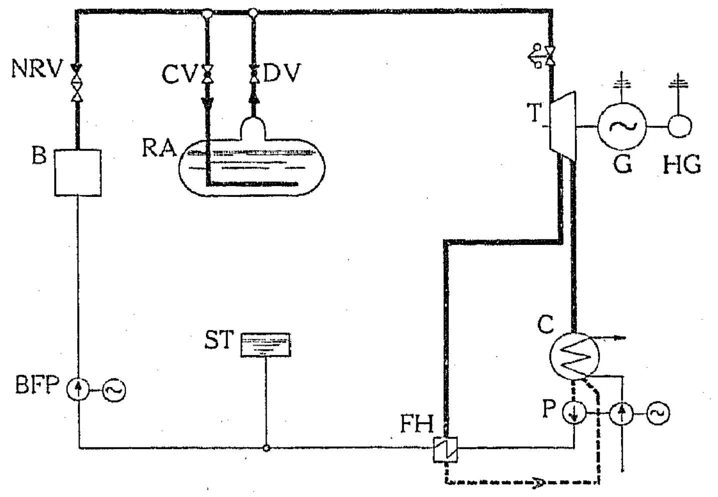


Fig. 12.—Elementary diagram of a stand-by plant with a Ruths steam accumulator.

B = Boiler.
BFP = Boiler feed-pump.
C = Condenser.
CV = Charging valve.
DV = Discharging valve.
FH = Feed-heater.
G = Main generator.
NRV = Non-return valve.
P = Condenser pumps.
RA = Ruths accumulator.
ST = Surge tank.
T = Main turbine.

Steam .. ▬▬▬
Condensate .. - - - - -
Water .. ———
Three-phase .. —|||—

An ingenious suggestion has been put forward by F. Marguerre,* who has proposed a thermodynamic accumulator working on the reversible heat-engine or heat-pump principle (see Fig. 13). During discharge, the electrical machine runs as a generator, driven by the turbine taking steam from the accumulator or high-level heat receiver. During charge, the electrical machine runs as a motor, driving the vapour compressor, which evaporates water from the low-level heat receiver and pumps it into the high-level one. In order to avoid having to construct the low-level heat receiver so as to withstand a vacuum, this receiver is designed as a displacement-type water container, the natural difference in density preventing the hot water drawn from or introduced at the top from mixing with the cold water returning to or coming from the bottom. The heat absorption and liberation take place in a separate jet-type condenser and evaporator respectively, which can readily be built to withstand a vacuum. The special advantages claimed for the scheme are the absence of any kind of combustion, with attendant fuel-supply and smoke nuisances, as well as of any extensive cooling-water system, thereby enabling the plant to be installed in residential areas. Only a very small amount of cooling water is required to balance the inherent losses. Difficulties associated with the practical realization and the high cost of the equipment have, however, prevented the scheme from being put into operation.

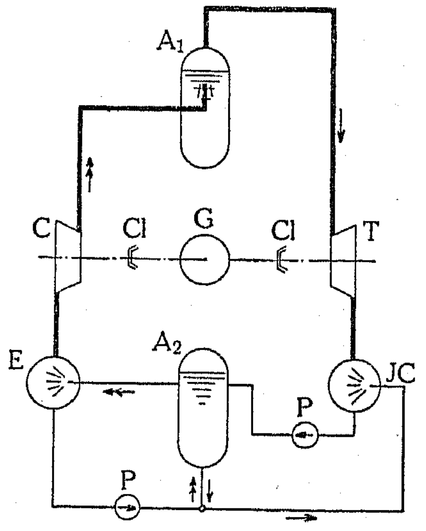


Fig. 13.—Principle of the thermodynamic accumulator energy-storage system proposed by Marguerre.

A_1 = High heat-level accumulator.
A_2 = Low heat-level accumulator.
C = Vapour compressor.
Cl = Clutch.
E = Evaporator.
G = Generator.
JC = Jet condenser.
P = Pump.
T = Turbine.
→→ = Charge.
→ = Discharge.

Probably the most promising variation of the steam-accumulator principle is the high-pressure bridging accumulator, which is charged to a pressure of the order of 1 800 lb. per sq. in. and is used only for bridging the short time-interval required for bringing the boilers into service. Fig. 14 shows a diagrammatic arrangement of an instantaneous stand-by station with a quick-steaming boiler and a bridging accumulator. The turbine is of normal design, and when running idle receives cooling and gland-sealing steam through a reducing valve from the small auxiliary electric or oil-fired boiler, used for charging the accumulator. Indeed, when electrical energy is used for this purpose, a separate boiler can be dispensed with and the electric heating element incorporated (as shown in the diagram) in the accumulator. The latter consists of a number of forged-steel drums, the metal alone representing about 30 per cent of the total heat-storage capacity, and is of moderate dimensions, as, with the quick-starting boiler, steam has only to be supplied during a few minutes. A throttling valve reduces the pressure down to the normal turbine value. The steam can also be superheated by passing it through a heating coil in a second accumulator of the same type. The condenser and boiler auxiliaries may be supplied either from the main alternator, in which case they are connected through an independent breaker directly to the machine terminals, or, preferably, from a house alternator coupled to the main unit.

---

* " The Marguerre Thermodynamic Storage System," International Union of Producers and Distributors of Energy, Fifth Congress, Zürich, 1934.

Mention may also be made of a practice, more common in the U.S.A. than in Europe, of installing turbines with a high overload capacity, involving a slight reduction of efficiency at economical load, the latter being of the order of 50 per cent or less of the maximum output. An alternative method of temporarily increasing the maximum output, employed in some Continental stations, is to shut off the steam extracted for feed heating, allowing it to develop energy by further expansion down to condenser pressure. The condensing plant must then be dimensioned for this maximum steam flow, otherwise the loss of output due to the falling vacuum may offset most of the anticipated increase. Moreover, an extra-large hot-feed storage tank, sometimes referred to as a constant-pressure accumulator, has to be provided, to ensure hot feed-water being supplied to the boilers for the duration of the overload. The first alternative achieves a rise in output of the turbo-set only, and does not solve the problem of a suddenly increased steam demand; whilst the small increase in output achieved by the second does not appear to justify the complication involved.

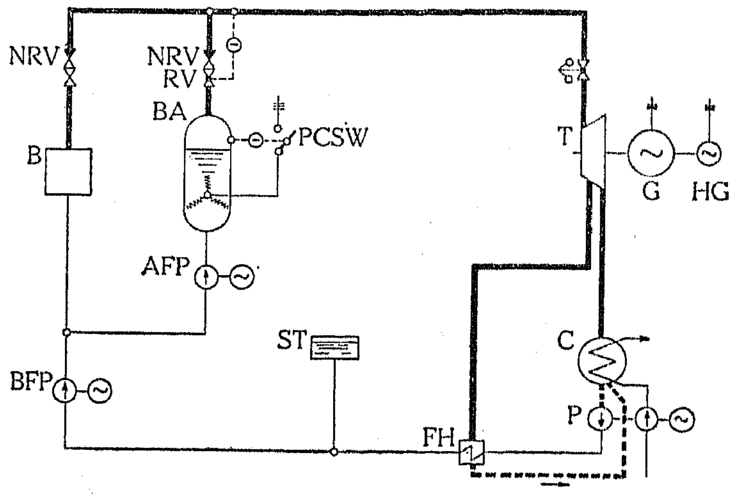


Fig. 14.—Elementary diagram of an instantaneous stand-by plant with high-pressure bridging accumulator.

B = Quick-steaming boiler.
BA = High-pressure bridging accumulator.
PCSW = Pressure-controlled switch.
RV = Reducing valve.
NRV = Non-return valve.
T = Main turbine.
G = Main generator.
HG = House generator.
C = Condenser.
P = Condenser pumps.
FH = Feed-heater.
ST = Surge tank.
BFP = Boiler feed-pump.
AFP = Accumulator feed-pump.

Steam .. ━━━━
Condensate .. - - - - -
Water .. ————
Three-phase .. —|||—

(6) AUTOMATIC AND SEMI-AUTOMATIC STAND-BY STEAM PLANTS

It is not to be expected that either surveying authorities or insurance companies will, for some time hence, countenance the running of steam power plants wholly unattended, but even though a staff has to be present the adoption of full or semi-automatic operation offers decided advantages. Not only does it enable a considerable reduction to be effected in the number of attendants, but also, by relieving them of routine duties, it allows them in times of emergency to give their full attention to problems arising out of unforeseen troubles in which the station may be involved.

The hitherto common practice of separating the boilers from the turbo sets, necessitating an extensive pipe system with numerous valves, does not readily allow the use of automatic control. This is not true of stations planned on the unit system, employing quick-steaming oil-fired boilers installed in close proximity to the turbines. Such boilers are indeed normally supplied with push-button control for starting, and are fully automatic in operation, whilst the use of contactor starters for feed pumps and condenser and other auxiliaries is now well established. The extension of the automatic apparatus to the complete power unit, enabling it to be controlled from a remote load-dispatching centre, does not, therefore, present any insurmountable difficulty.

It is beyond the scope of this paper to describe in full the application to steam stations of the remote supervisory control systems developed during the last two decades for automatic substation and hydro-electric plants, but it may be of interest to mention briefly the sequence of operations and other details.

The sequence in the case of an installation with a Velox boiler is:—

(*a*) Boiler feed-pump started.
(*b*) Boiler circulating-pump started.
(*c*) Air compressor run at reduced speed.
(*d*) Electrical ignition switched on.
(*e*) Fuel pump started.

As soon as the fuel emerges from the burner, it is lit by the electrically-heated ignition element. The starting operation is concluded as follows:—

(*f*) Ignition switched off by a photo-electric relay.
(*g*) Air compressor accelerates as gas-turbine output increases with rising temperature.
(*h*) Steam-pressure regulator takes over control of fuel and air as soon as normal pressure is attained.

To prevent corrosion, the boiler may be kept normally completely filled with water. At the moment of starting, while pressure is being raised, an electrically- or hydraulically-operated valve drops the level to normal, a contact device on the water-level indicator causing closure when the normal level is reached. A small drain valve beyond the superheater opens and remains open until full pressure is established, i.e. until all the water in the superheater has been driven out and only steam passes through, whereupon this drain valve closes and the main stop-valve opens. If the plant is of the instantaneous type with bridging accumulator, the turbine is already running, and will now receive steam from the boiler instead of from the accumulator, which is then automatically isolated. In cases where the set is not already running, vacuum is raised by a high-capacity starting ejector, and an additional control device causes the turbine governing valves to regulate the steam admitted, limiting the acceleration to a predetermined value. If necessary, the unit is then paralleled by means of an automatic synchronizer.

The devices requiring particular consideration are those designed to replace the human element in protecting the equipment against abnormal conditions. These consist of:—

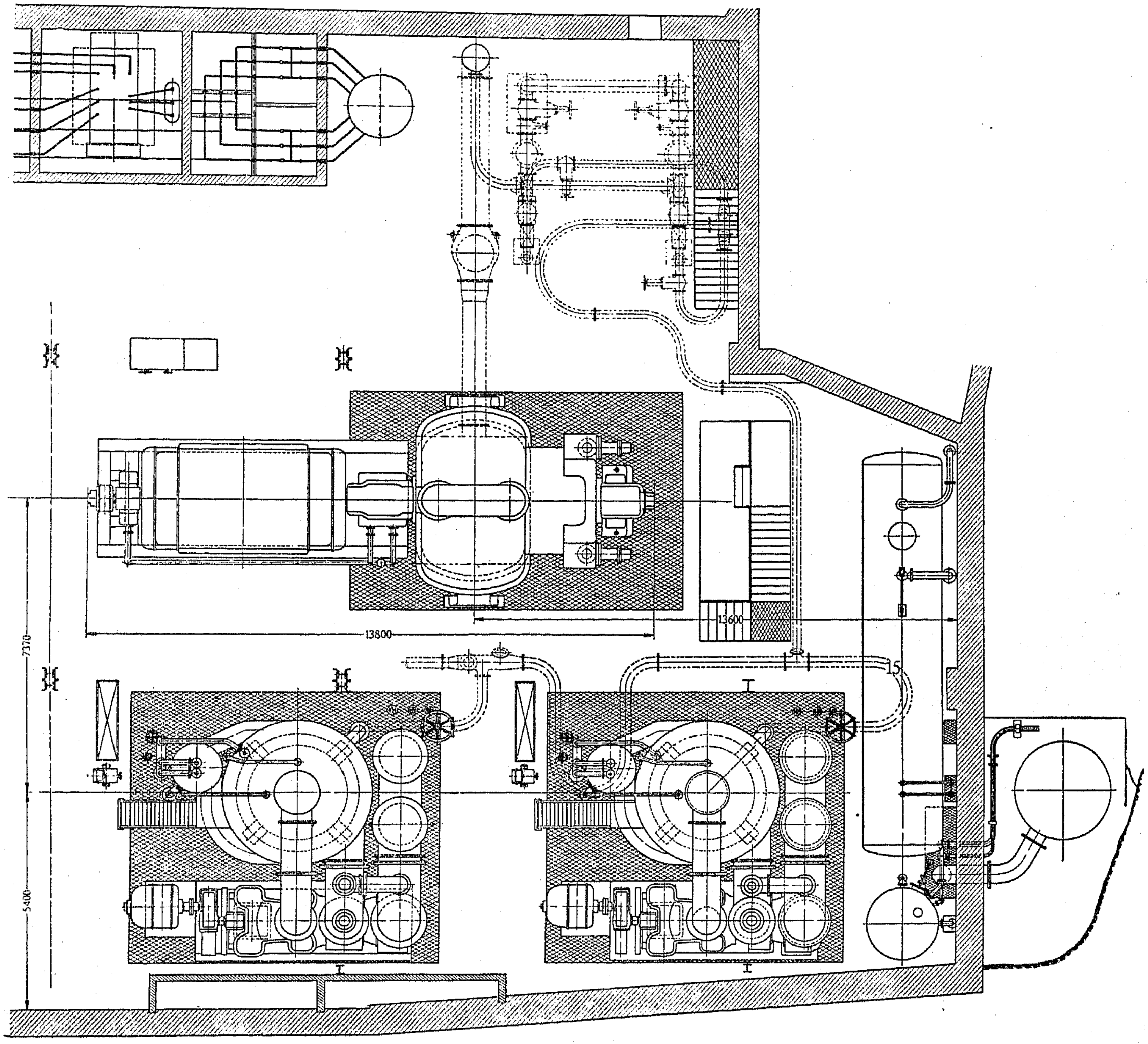


Fig. 15.—Plan of the 31 500-kW stand-by plant of the City of Oslo (dimensions in millimetres).

(A) *For the boiler.*

- (i) High and low water-level protection.
- (ii) Circulation-failure protection.
- (iii) Automatic re-ignition by a photo-electric relay, if flame should become extinguished on low load.
- (iv) Protection against the continuous emission of an excessive volume of smoke, by photo-electric and alarm relays.

(B) *For the turbine.*

- (i) Overspeed protection.
- (ii) Protection against lubricating-oil failure as well as against excessive bearing temperature.
- (iii) Protection against excessive vibration.
- (iv) Protection against abnormal steam-pressure gradient over blading or loss of vacuum.

All the above protective devices, with the exception of the smoke detector, which actuates local and distant alarms, operate to shut down the plant should the abnormal condition persist, and to show, by means of an indicator relay, the cause of the shut-down.

(7) NOTEWORTHY STAND-BY STEAM-PLANT INSTALLATIONS

The first Ruths installation for stand-by service was laid down in 1922 for the city of Malmö.[*] The accumulator operates over a pressure-range of 100 lb. per sq. in. down to 14 lb. per sq. in. (gauge) and supplies the full-load steam requirements of a 3 750-kW turbine during some 50 minutes.

The largest Ruths plant constructed to date is that erected during 1928–29 in Germany as an extension of the existing Charlottenburg generating station.[†] It consists of 16 accumulator drums, each 70 ft. high by 15 ft. diameter and of 11 000 cu. ft. capacity, which for economy of space were installed vertically, and two 20 000-kW special turbines for operation with saturated steam at between 180 and 7 lb. per sq. in. (gauge). The installation was designed to furnish 40 000 kW for 1 hour, or 50 000 kW for 45 minutes.

The first high-pressure bridging accumulator plant was installed last year at the Simmering power station, Vienna.[‡] It consists of 8 forged-steel drums, each 30 ft. long, 4 ft. in diameter, and 3 in. thick. Two of the drums have coils through which passes the steam from the others, the coils acting as superheaters. The steam is expanded through a reducing valve from 1 700 to 500 lb. per sq. in., and leaves the superheating drums at 580° F. It is destined to enable the demand arising from the sudden failure of one or other of the main hydro-electric transmission lines supplying the town to be met during the time required to raise steam in a La Mont type boiler provided with auxiliary oil firing.

The first supercharged quick-steaming boiler for peak-load service was erected in 1933 at the Toulon plant of the Société du Gaz et de l'Électricité du Sud-Est, in the South of France. The boiler has a rated output (continuous) of 55 000 lb. per hour at 285 lb. per sq. in. (gauge), 710° F., and is used throughout the winter months, being started up daily shortly before dusk and shut down again at about 10 p.m. after the lighting load has passed its peak.

The most important installation hitherto equipped with this type of boiler is that of the Oslo electricity undertaking, which was commissioned at the end of 1936.[*]

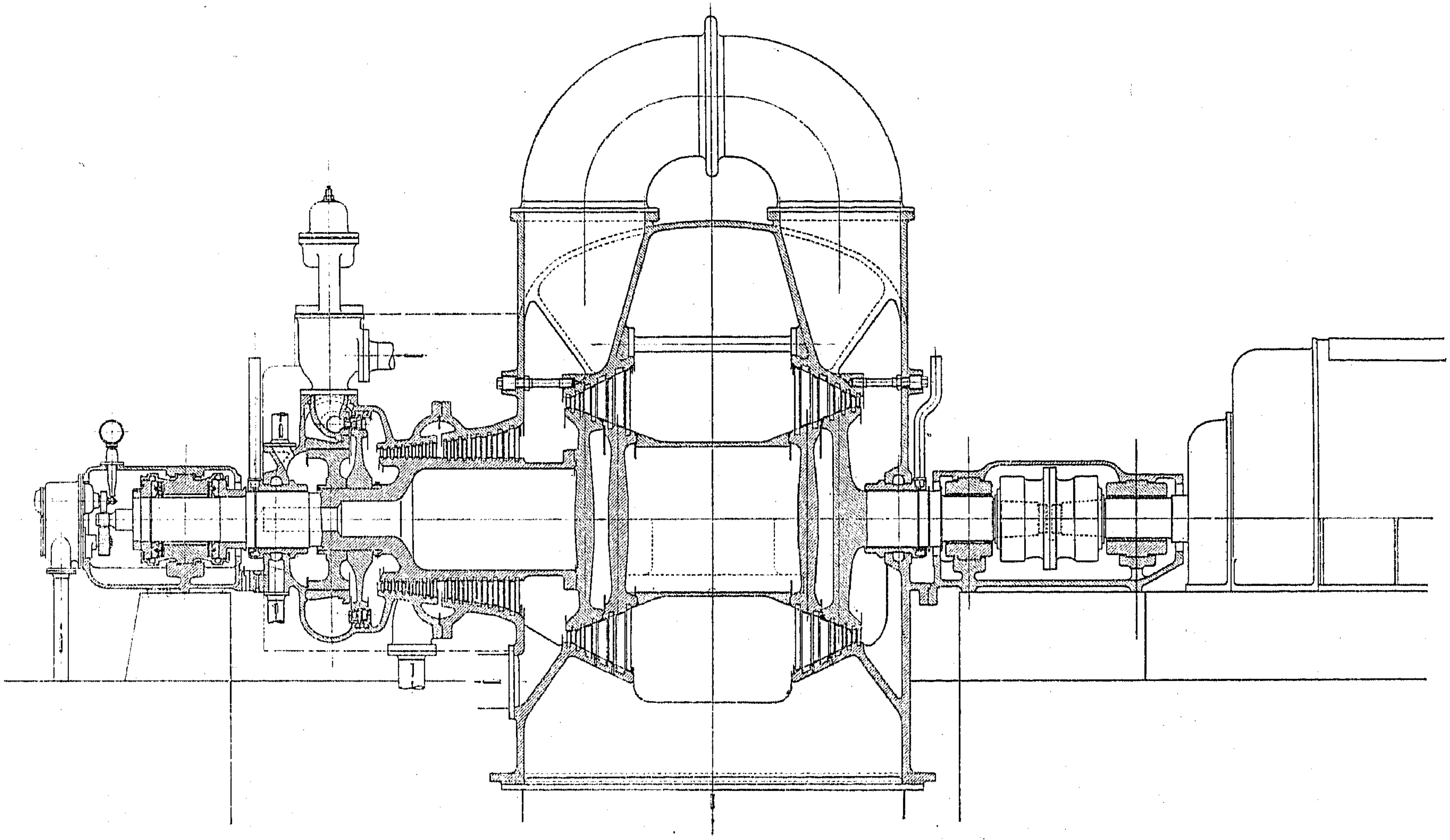


Fig. 16.—Section of the 31 500-kW single-cylinder steam turbine at the stand-by plant of the City of Oslo.

It comprises one 31 500-kW 3 000-r.p.m. 6 600-volt turbo set for 385 lb. per sq. in. (gauge), 800° F., which, together with two 165 000 lb. per hour Velox boilers, the step-up transformer, and the switchgear, has been accommodated in about two-thirds of the space previously occupied by the water-tube boilers supplying two 6 000-kW sets (Figs. 15 and 16). The station assists the distant hydro-electric plants during occasional periods of water shortage in the winter, and is also intended for use as a stand-by in the event of a breakdown on one or other of the main incoming high-voltage lines. Although not especially designed for quick starting, all auxiliaries being provided with simple hand-operated control gear, it

[*] J. Ruths: "Meeting Peak-load Demand in Large Central Stations," *Elektrotechnische Zeitschrift*, 1927, vol. 48, p. 916.

[†] W. E. Wellmann: "Tests on a 50 000-kW Ruths Storage Plant," *Zeitschrift des Vereines Deutscher Ingenieure*, 1930, vol. 74, p. 743.

[‡] F. Stipenitz: "Quickly-Available Power Plant with 1 700 lb. per sq. in. Accumulator," *ibid.*, 1937, vol. 81, p. 1039.

[*] A. Fischer: "The Rosenkrantzgate Steam Power Station of the Oslo Electricity Works," *Brown Boveri Review*, 1937, vol. 24, pp. 203 and 235.

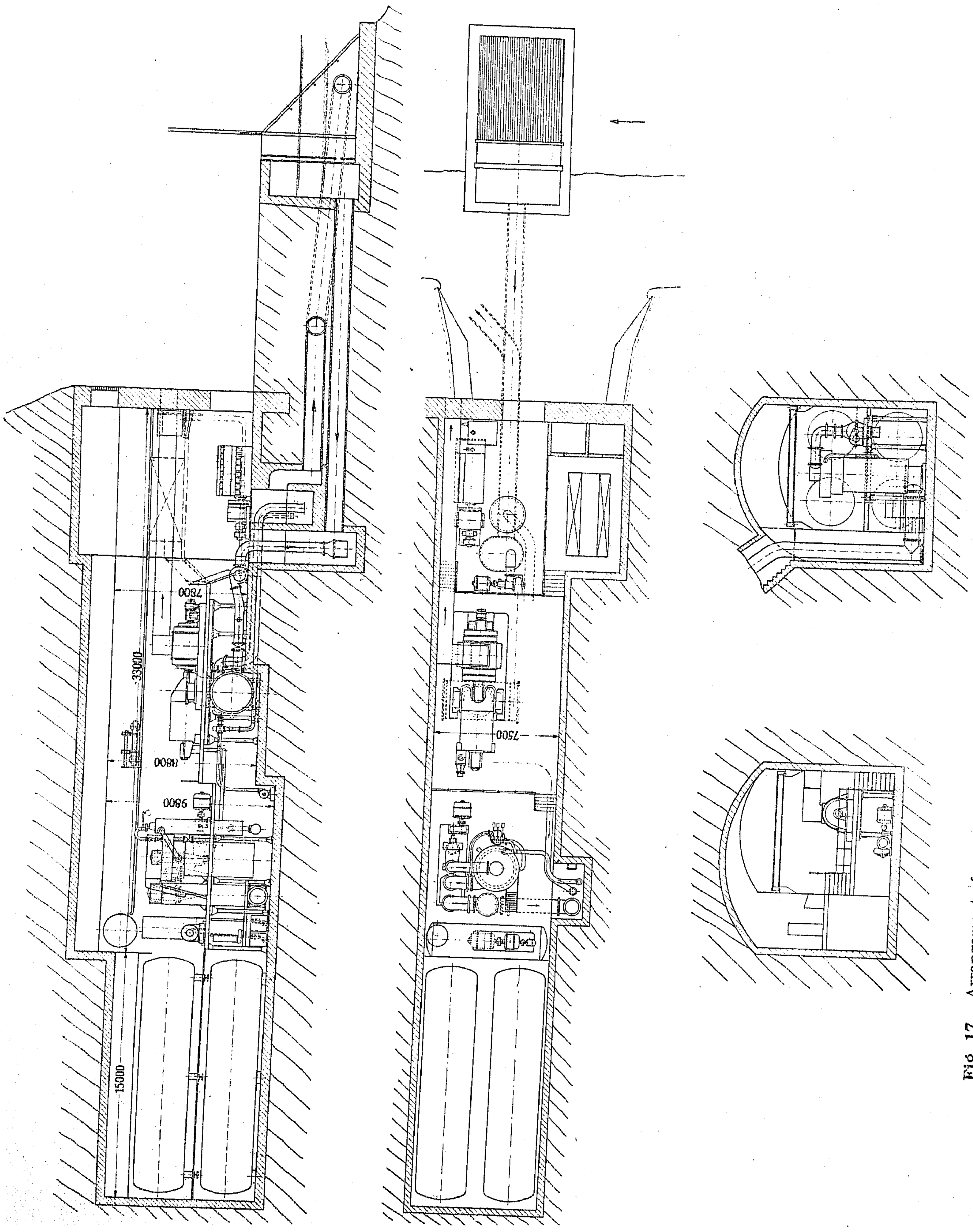


Fig. 17.—Arrangement of an underground bomb-proof stand-by steam power-plant for an output of 10 000 kW.

can be put into service within 20 minutes. As the plant operates mainly in the winter, when the temperature of the cooling water is only just above freezing point, the turbine is provided with a double-flow low-pressure section for utilizing the consequent high vacuum; but with normal cooling-water temperature there would have been no difficulty in designing a 3 000-r.p.m. machine for this output with a single exhaust.

Unthinkable a few years ago, the bombproof emergency-service station is now a grim reality. Some measure of protection of essential equipment against damage by fragments from stray shells or bombs can be provided by the use of sandbags, but these are of little avail against repeated attacks from the air on such an easily-located and inviting target as a large steam power station; particularly if the attacks come as a surprise, before any defence organization can be brought into action. The necessity of reckoning with such an eventuality has led to the construction in several countries on the Continent of bombproof stand-by power plants, for the maintenance of the essential services of towns or districts, and/or supplying the power requirements of munition factories. According to the particular circumstances, these plants are either of the surface or of the underground type. Fig. 17 shows the arrangement of such a station for an output of 10 000 kW, located in a tunnel cut into the cliff face. The turbo set, boiler, tanks containing sufficient fuel for 7–10 days' service, and auxiliary starting set, are accommodated in a gallery some 150 ft. long, and of about the section of normal double-track railway tunnel. Where ground conditions are not favourable to such a disposition, or the danger of flooding exists, a station of the surface type is adopted, with roof and walls of reinforced concrete about 4 ft. thick, having the appearance of a block of dwelling houses or made inconspicuous in some other way. Although this last construction is not proof against a direct hit by a large bomb dropped from a considerable height, the chances of such a direct hit are so small as not to justify the extra cost of the necessary additional protection.

(8) ACKNOWLEDGMENTS

In conclusion, the author wishes to acknowledge his indebtedness to Prof. W. M. Thornton, O.B.E., D.Sc., D.Eng., to whose encouragement the present paper is really due, also to the chief engineer (Dr. Adolphe Meyer) and the directors of Messrs. Brown, Boveri & Co., Ltd., of Baden, Switzerland, for permission to publish the same; and to his colleagues, in particular Messrs. Felix, Meldahl, Seippel, and Spoerli, for helpful criticism of the manuscript draft and many valuable suggestions

DISCUSSION BEFORE THE INSTITUTION, 10TH NOVEMBER, 1938

Mr. Johnstone Wright: The author's summary of the various applications which have been made of thermal power plants for emergency and peak-load services defines three classes of plant, namely emergency service, occasional service, and regular peak load.

To give a full emergency service means that in addition to the normal source of supply additional capacity has to be provided, which can be brought into use rapidly in the event of failure of the normal source. It seems to me that this is a practicable proposition only in very special cases. One such special application is where the normal supply comes from distant hydro-electric stations over very long transmission lines traversing difficult country and where the frequency of line outage is probably higher than in the case of more normal transmission lines. In cases of this sort there is also frequently the possibility that during abnormal seasons there may be failure in the water available for the hydro-electric stations. The latter reason may itself justify the use of special plant at the load centre. Where the difficulty is the possibility of line outage it seems to me quite uneconomic to provide the very large amount of additional generating plant required to give this emergency service. It is much better to obtain the necessary security by a suitable division of the supply lines so that all likely outages will still leave adequate capacity available. In the general conditions which exist in Great Britain I certainly do not think there is likely to be any great demand for special plant for emergency service—at all events not for large plants. Such institutions as hospitals will of course mean some demand for small plants.

The field of application of plant for occasional service appears to me to be still more limited. The conditions envisaged by the author would appear to be dealt with more effectively by arranging that the regular peaking plant can be put into commission at short notice.

To me, the most interesting section of the paper is that which deals with plant for regular peak-load purposes. Figs. 1 and 2, and particularly Fig. 2, indicate conditions which are typical of most electricity supply undertakings. The higher values of maximum demand have to be met over a relatively small proportion of the year.

The instances the author gives of the application of the Velox boiler are of great interest. The Oslo plant is perhaps fortunate in that, although situated at the load centre, it has access to very ample and satisfactory sources of water for condensing purposes. There are many places where peak-load plant might in future have to be installed in this country, where supplies of circulating water are much less favourable, and such stations will require cooling towers. It may well be that the space required by these cooling towers will be the determining factor in the capacity of peaking plant which can be installed on such sites.

When it becomes necessary to consider the design of special stations in this country for peaking purposes, I hope the manufacturers will be able to put forward proposals for plants which, although not working at the highest efficiencies, do have overall costs very materially less than those of the normal plant at present being installed. Such peaking plants do not necessarily require to be put into commission at very short notice, but it is certainly an advantage if this provision can readily be made. In this connection, the Velox boiler and the arrangements of turbines shown in Figs. 7 and 16 are very interesting. The performance of the Velox boiler in this respect is certainly exceptional. Unfortunately, at the present time it appears to be capable of burning only oil and similar fuels, whereas in this country it is essential that all boilers, whether for peaking or for other purposes, should burn coal. I know that the author's firm are working on this problem, and hope they may have success.

Under the conditions obtaining in this country a considerable amount of generating plant is only run up for 2 or 3 hours a day, and it is desirable that all future machines should be designed to permit of such frequent starting and stopping. It must be remembered that even plant which is designed to give very high efficiencies may only be economical for use on base load for the early years of its life. At the end of such a period it may well be superseded by still more efficient plant, and may then be relegated to less continuous service. Towards the end of its life it is by no means unlikely that such plant might have to be used as peaking plant, and have to be started up and stopped every day.

I am interested in the author's remarks regarding the design of turbine rotors and casings for peak-load and emergency services, in order to guard against distortion during rapid running-up or during shutdown periods. This subject appears to justify considerable further research into the proportions of fabricated rotors and the materials used in their construction.

The author refers on page 317 to the practice, more common in the U.S.A. than in Europe, of installing turbines with a high overload capacity. In this connection, the late Sir Charles Parsons advocated the use of such turbines in which the economic rating was only some 50 per cent of the maximum continuous rating. He expressed the opinion that the turbine could be operated at economic loading with an efficiency only 1 or 2 per cent below that of a standard machine and that, moreover, the rotor would remain true and free from vibration even when brought up quickly to the maximum continuous load. When discussing this subject before the World Power Conference in 1930, Sir Charles expressed the opinion that in this way peak-plant capacity could be provided for an all-in incremental cost of between £4 and £6 per kilowatt, inclusive of boiler plant and buildings. If we could get peaking plant at this price, plus the increase in cost of labour and material since 1930, then there would be a market for such plant, but recent figures I have considered do not encourage me to hope for anything of the kind.

Mr. C. L. Blackburn: The reason why we in this country have not installed more peak-load plants is undoubtedly one of economics, the only justification for peak-load plant as distinct from emergency plant being the financial saving.

I should like to refer to Mr. Johnstone Wright's remarks regarding the economic price of peak-load plant compared with that of base-load plant. Suppose, for example, it is known that a co-ordinated generating system, such as that in South-East England, will in a few years' time require 100 000 kW of plant, and we have the opportunity of choosing either base-load or peak-load plant. If we choose the base-load plant it will probably generate 600 million units in the course of a year, but if we install peak-load plant practically the whole of those 600 million units will have to be generated elsewhere, by the existing stations, since the peak-load plant—being designed for low capital cost rather than high efficiency—will generate very few units. The new base-load plant will be more efficient than the average run of existing plants. A saving of 0·01d. per unit, for example, would yield £25 000 a year on an output of 600 million units. An examination made recently of typical costs for this country showed, however, that the total saving might be 4 times that amount, or about £100 000. In other words, the peak-load plant starts with a handicap of £100 000 a year, or £1 per kW per annum, corresponding to at least £8 or £9 per kW of capital cost. On this basis, considering capital costs, the £14 per kW given by the author for the base-load plant must be compared with £15 per kW for the peak-load plant, instead of with £7 per kW as his diagram showed. These figures explain why there must be a very large margin between the capital costs of peak-load plant and of base-load plant if the former is to show a financial advantage.

The comparison I have given is rather an extreme one, as it assumes base-load plant which is going to run almost continuously and peak-load plant which will run scarcely at all. A great many units are in fact generated by stations which run at intermediate load-factors, and the design of such stations deserves careful consideration. In Table 1 the author considers only peak-load plants operating up to 17 per cent load factor, but we should also consider the economic basis of design for stations having load factors from 17 per cent up to the 70 per cent of the base-load plants.

The author mentions at the end of Section (5) the provision of extra overload capacity for emergency service; this is very useful in the event of breakdown of other sets in the power station. Examples of this type of plant are the turbo-generators now being manufactured in this country for Cape Town, which are normally rated at 40 000 kW and have a capacity of 50 000 kW for 2 hours, provided that special conditions of loading obtained before the extra load was put on. Methods of temporarily increasing the output of boilers at some sacrifice of efficiency are also well worth consideration.

There is a distinct advantage in carrying an emergency load on plant which is already running, rather than having to bring into operation plant which is standing, even though this may be specially designed for quick starting.

Under conditions when the possibility of destruction by bombardment has to be provided against, the Velox boiler and the internal-combustion engine must be seriously taken into consideration, even with oil as expensive as it is in this country, and the normal economics of power-station design become very much distorted by the necessity of providing compact equipment. We are, in fact, approximating here to the considerations involved in marine design.

Dr. A. Meyer: I should like to supplement the paper by a few words about a bombproof power station ordered about 6 months ago by the town of Neuchatel, in the French part of Switzerland, where the prime mover is a gas turbine. All the various possibilities for driving this station were considered, and the figures showed that the cost of such a station equipped with a gas turbine, with a Velox-boiler steam plant, and with a Diesel engine respectively, would be roughly in the ratio 1:2:3. The final decision, therefore, was in favour of the gas turbine, and the machine installed is of the continuous-combustion type. The axial blower takes its air directly from the atmosphere and compresses it into the combustion chamber; part of it is used to burn the oil, and the rest is passed round the burner and used for getting the temperature of combustion down from about 2 000° C. to the temperature which the blades of the gas turbine will stand, about 550° C. (1 000° F.). From the gas turbine the gases flow directly to the chimney.

The simplicity of such a machine will be appreciated. There is no boiler, no feed-water treatment, no condensing plant, no cooling tower, and no need for any water at all, so that the plant can be placed wherever desired. The possibilities of such a plant are mainly dependent upon three factors. There is, first, the temperature that the blading of the gas turbine is able to stand. Secondly, the efficiency of the blower supplying the compressed air for combustion purposes is all-important; we want not merely the air for combustion plus a little excess air but about 3–4 times the amount used for combustion, because we have to cool the gases before they enter the gas turbine. Thirdly, of course, the efficiency of the gas turbine itself is important.

In the case of a gas turbine with a total efficiency of 53 per cent the efficiency of the cycle is zero; the turbine is just able to drive its blower, but can do no more. At 2 000 kW we have an efficiency of 73 per cent, and obtain 17 per cent cycle efficiency on the coupling without reheating; and at 4 000 kW we get a figure of 18 per cent. Total efficiencies of 70 per cent or more were not possible with the old centrifugal blower; such figures can be attained only with axial blowers, which have been developed together with the Velox boiler on the basis of our present knowledge of aerodynamics.

Mr. W. M. Selvey: An eminent French engineer recently said that with the system of transmitting large base-load blocks of power from the South of France to Paris it is impossible to provide for the safety of the Paris supply unless a very substantial steam stand-by is built up.* The trouble arises from the extra hazards associated with many miles of high-voltage conductors. Those hazards mean that an additional capital commitment, in the form of stand-by thermal plant, must be assumed in arriving at the commercial value of the hydro-electric power in the South of France.

The question of the provision of peak-load plant also arises in Germany, a country which does not rely on water power to any considerable extent (though it is now proposed to develop it upon a larger scale in Austria). A heavy base-load has been placed on the brown-coal stations of Germany, and in consequence base load has to be transmitted. Further, many chemical works have installed super-pressure boilers equipped with "topping plants," a class of equipment which cannot be relied upon for continuous service in the way that the Central Board have to rely upon our own main stations.

To make a broad generalization, we in Great Britain do not transmit our base-load power, because our base-load stations consume a large proportion of their total output. Of all the countries in the world Great Britain has done the least of what is called "economic planning." It should be possible to discover, in regard to any community which depends very largely for its essential services upon the continuity of electricity supply, the minimum local plant necessary for the maintenance of those vital services should that community be cut off from other parts of the co-ordinated system.

We may hope that for a considerable time yet our new base-load plants will have an appreciable gain in efficiency over the existing ones. I think, therefore, that we must continue to encourage our manufacturers by always buying base-load plant. We make so much use of these plants that the saving on running costs represents a considerable item of capital cost, which has to be balanced against the cost of the "cheap" peak-load plant.

Mr. W. S. Burge: In his opening remarks the author stated that in Great Britain, where a comprehensive scheme of interconnection is in existence, he did not think it likely that a case could be made out for a station designed especially for the purpose of meeting peak-load and emergency conditions. It is probable that he has in mind the fact that the tide of progress during the last 20 years has always left in its wake an accumulation of plant which, although in various stages of technical obsolescence, had not yet lived its useful life of 20 years and can therefore be conveniently employed for peak-load duty. The fact that the grid scheme in this country provides the necessary interconnection between all categories of plant affords an excellent means of utilizing these various categories in the most efficient manner.

It will enable us better to appreciate the ordinary course of technical progress if we visualize the duration load curve shown in Fig. 2 and consider that throughout the history of our power-station industry the normal drift of things has been for the base-load plant of the present to become the peak-load plant of the future, while at the same time the peak load of the present becomes the base load of the future. Bearing this tendency in mind, it becomes evident that any new peak-load plant which is designed and constructed for this specific purpose will have to be installed for an extraordinarily low cost if it is to be placed towards the top of the duration curve immediately it is built, because the proportion of standing hours even in the early stages of its life must of necessity be very excessive, and it must furthermore be remembered that if new plant is bought in towards the top of the duration curve it will, in effect, block the natural progress of older plant when it travels up the duration curve as a result of being superseded by high-efficiency base-load plant.

The author does well to stress the importance of reliability in regard to power-station auxiliary drives, but, as in many other matters, simplicity is synonymous with reliability and I cannot help feeling that some of the methods illustrated by him are anything but simple. Looking back on past experience, my mind centres on the very simple scheme used in the original Carville power station some 25 years ago, in which the auxiliaries were arranged on the complete unit system with optional cross-connection facilities for use if necessity arose, and I believe that for any normal power station that system still represents sound and reliable practice to this day.

---

* See *Electrician*, 1938, vol. 120, p. 805.

Turning to the question of steam conditions, I am interested to note that the author, in his search for cheap peak-load designs, does not assume that the old low-pressure steam conditions of 20 years back would be the cheapest conditions for to-day. My impression is that, with the present tendency towards standardization at pressures of about 600 lb. per sq. in. and temperatures of about 800–850° F., these steam conditions may with careful design represent the lowest over cost for a power station as a whole, but if the deliberate intention is to produce a plant at the lowest possible cost per kilowatt installed, then one might achieve this end by maintaining these modern steam conditions at the stop-valve of the turbine, and reducing, as far as possible, the volume ratio across the turbine and the temperature ratio across the boilers. I suggest, for instance, that instead of the usual figures of between 28 in. and 29 in. vacuum, we might with advantage employ 25 in., and instead of our usual stack temperatures of, say, 270° F., a temperature of 600° F. might be employed. Admittedly, this would result in a deliberate sacrifice of efficiency, but, since capital cost is our primary object, I suggest that a peak-load station might very well follow these lines. An efficiency analysis for a station operating at 600 lb. per sq. in. and 800° F., with 25 in. vacuum and 700° F. stack temperature, shows that a maximum efficiency of 18·3 per cent might reasonably be expected and that for occasional peak-load operation with extended periods of banking this efficiency would probably be reduced to about 15 per cent.

I note with interest the author's remarks in regard to the use of single-cylinder turbines at 3 000 r.p.m. for capacities up to 50 000 kW, and while I quite agree as to the practicability of designing for this total capacity at 3 000 r.p.m. I do not agree that a reliable single-cylinder machine could be built for these conditions. The turbine shown in Fig. 7 rather puzzles me because, although it is put forward as a machine with quick-starting characteristics, it has a fabricated rotor, and I cannot help feeling that for large capacities in a single cylinder where the temperature gradient across any given mass of metal is bound to be rather excessive, such a construction would give anything but reliable or quick-starting characteristics. British practice indicates that the forge masters of this country are capable of producing entirely reliable forgings for rotor dimensions up to 36 in., and if these rotors are cut out of the solid forging then excessive hub stressing is eliminated, and for this reason the pitch between adjacent stages can be greatly reduced, with resultant reduction in overall length between bearings for any given cylinder. If a machine is deliberately designed for a low total volume ratio (i.e. for low vacuum) and if a total capacity of 50 000 kW is put into two cylinders, then the solid-rotor construction can be used throughout the whole machine with resultant very good running characteristics, and the cost may be less than that of a fabricated-rotor machine in one casing.

So far as the Velox boiler is concerned, if I were looking for a forced-circulation boiler I should try to avoid one that carried with it a gas turbine as an auxiliary item.

Mr. G. L. E. Metz: One of the first duties of thermal plants for peak-load and emergency service is to render a supply at a cost that can be justified on economic grounds. It is therefore disappointing that the author does not give the costs of the plants described in the paper. It is known that the costs of thermal plants vary in different parts of the world; but the figures given in Table A, which apply to peak-load thermal stations in Sweden, may be of interest. These figures compare favourably with the cost of a modern base-load steam station in this country, which had been given recently as £14 to £17 per kilowatt installed. The peak-load stations referred to in the Table are much simpler than a modern high-efficiency base-load station. The prices ruling on the Continent are generally lower than those prevailing in this country, and this accounts for some of the difference in cost.

Table A

APPROXIMATE COST OF THERMAL PEAK-LOAD STATIONS IN SWEDEN IN 1936*

kW	Cost per kW installed
50–500	£35–£22
500–5 000	£22–£10
5 000–10 000	£10–£6

* The figures of kilowatts installed represent the maximum continuous rating of the plant. The figures of cost include boilers with accessories, turbo-alternators with accessories, building, and chimney, but exclude the distribution equipment.

On page 310 it is stated that high efficiency is of minor importance compared with capital cost. I would point out, however, that the cost of a turbo-alternator of high efficiency is not necessarily much more than that of a low-efficiency machine. Under these circumstances it is a distinct advantage to use an efficient turbo-alternator because the lower steam consumption obtained reduces not only the running costs but also the size and cost of the boiler. A reduction of 10 per cent in the steam consumption might consequently result in appreciable savings in the cost of the plant as a whole. It is for this reason that I suggest that the author's statement on the subject needs some qualification.

It is unfortunate that he attempts to deal with quick-starting turbo-alternators for peak-load and emergency service on the assumption that all turbo-alternators have similar characteristics irrespective of their design. The differences which distinguish turbo-alternators for ordinary base-load service may not be very marked, but in the case of machines for more particular forms of service these differences become serious enough to make generalizations most misleading.

I should like to point out that the remarks on page 312 regarding the thermal stresses in the casing and rotor shaft of axial-flow turbines do not apply in the same way to a radial-flow turbine, which has no long and heavy rotor shaft. For this reason I suggest that when quick starting is being considered it is helpful to divide turbo-alternators into two classes: one class embracing axial-flow machines of the usual type, where the minimum starting time is to some extent connected with the length and size of the rotor and therefore with the thermodynamic efficiency; the other class embracing radial-flow machines such as the Ljungström type, where the minimum starting time is independent of the thermodynamic efficiency.

It is not always appreciated that a high-efficiency axial-flow turbine generally has more stages and a longer and heavier rotor shaft than a low-efficiency machine, and is therefore not particularly well suited to quick starting. This characteristic of axial-flow machines makes it difficult to provide high thermodynamic efficiency and quick starting in many cases, with the result that a compromise must be made; whereas the radial-flow machine can be designed to give high thermodynamic efficiency and quick starting, and is for that reason particularly suited to peak-load and emergency service.

The starting times given at the top of col. 1 of page 312 presumably relate to axial-flow machines; it would be interesting to know the thermodynamic efficiency of the machines to which these times relate, and also the time required to reach full load in each case.

The figures given on page 313 for the Forrsblad boiler do not do it full justice. Two Forrsblad boilers have been installed at a peak-load thermal station in Västerås, Sweden, and the starting time recorded at this station for a 50 000-kW turbine with a thermodynamic efficiency of 90·3 per cent, from cold water in the Forrsblad boiler to full load on the turbine, is of the order of 10 minutes. This figure compares very favourably with the starting time given on page 315 for the stand-by plant of Wellington City Corporation. It would be interesting if the author could give the time from cold water in the Velox boiler to full load on the turbine, in the case of the Wellington installation. I have heard that this is of the order of 30 minutes.

Do the efficiencies given in Fig. 11 include the auxiliaries? If not, it would be interesting to know the efficiency of the Velox boiler when the auxiliaries are included. I mention this because I am under the impression that the auxiliaries needed with a Velox boiler absorb rather more power than is taken by conventional boilers.

Mr. G. Lönnegren: It is noteworthy that the principles upon which the design shown in Fig. 7 is based are similar to those which are the foundations of all radial-flow machines. The radial-flow double-rotation turbine is ideal from a quick-starting point of view, and it is therefore to be regretted that the author devotes only two lines to this type of turbine.

In the radial-flow turbine, high-pressure steam enters the centre of the turbine and expands radially; high steam pressure and high temperatures are consequently confined to the centre of the turbine. This is of importance, because those parts which are exposed to high temperature are all located near the centre of the turbine where the mechanical stresses are low. The whole design is arranged to allow the machine to " breathe " under the influence of thermal stresses. The blade rings of large diameter are at low temperature and have to be designed for the stresses caused by the centrifugal force only. All parts exposed to a large temperature-drop are united by special flexible joints. The blade rings are connected to the turbine discs by means of flexible expansion rings. The turbine discs are subdivided into several sections, flexibly connected to each other by expansion pieces. All parts are of small dimensions, and the material can consequently be carefully checked and suitably selected to withstand such stresses as occur even at very high temperatures. The difficulties experienced in axial-flow turbines due to the uneven heating causing unilateral and corresponding deflections of shafts and drums, can hardly arise in a radial-flow double-rotation turbine, owing to its symmetrical arrangement. If, for instance, the upper half of the turbine casing became locally heated only a lowering of the outer ends of the two generators would take place relative to the turbine casing, and the inner ends of the shafts would make a symmetrical and equal movement upwards. The turbine shafts are very short, and the small deflections due to uneven heating are therefore negligible.

I should like to emphasize some of the points which make radial-flow turbines the most suitable type for peak-load and emergency service. The design of the radial-flow double-rotation turbine enables it to be started as quickly as it is possible to open the valves and to start the auxiliaries, and experience has shown that even with the largest units no special precautions need be taken in starting, stopping, and normal running. The turbine is insensitive to varying load conditions and can also be restarted immediately after being stopped, without any waiting time. There has not been the slightest evidence of risk of danger arising from temperature stresses. The author is perfectly correct when he states (page 311) that a high vacuum must be obtained when starting a Ljungström turbine quickly to take over full load, because no turbine can deliver its rated output without a fairly high vacuum in the condenser, but he is most certainly incorrect in implying that this fairly high vacuum is essential to prevent distortion of the turbine casing and resulting misalignment of the machine. Radial-flow double-rotation turbines start generally against a vacuum of about 80 per cent, but there is nothing to prevent them running non-condensing in an emergency, and therefore there can be no question of a dangerous misalignment resulting.

To get the right idea of the quick-starting characteristics of the double-rotation turbine it is necessary to consider the fact that the turbine in opposition to the axial-flow turbine can be started directly without any warming-up period. The starting of a double-rotation turbine, whether cold or warm, can therefore best be compared with the starting of an axial turbine, for which special methods of " keeping the turbine warm and the shaft straight " are used (page 312). The starting times given for these conditions compare fairly well with the starting times which can be obtained with the double-rotation turbine.

It is obvious that this permanent availability of the cold turbine for quick starting without any special precautions is a very great advantage of the double-rotation system. Because the turbine can be run up practically as fast as wanted, it is possible and also preferable to defer the starting-up of the turbine until all auxiliaries are running and a certain vacuum is obtained. It is quite possible to start at a lower vacuum, but this only means that a lot of steam is exhausted to the condenser at bad vacuum, thus increasing the load on the ejectors and the time necessary to reach full vacuum.

To facilitate quick starting, a special rapid-acting ejector is installed which enables the vacuum of 80 per cent to be obtained in less than 2 minutes. After this brief period the turbine can be started and run up to full speed in a further 2 minutes, at the end of which it is capable of taking over the full load immediately. The complete starting period from cold is thus only 4 minutes, and the whole starting operation can easily, if necessary, be carried out by one man, even for the largest set. A total starting time of 4 minutes only has actually been achieved with a 50 000-kW Stal turbine in Sweden. This turbine is of the high-efficiency type (thermodynamic efficiency 90·3 per cent). The above figures for the starting time of the turbine refer to the condition where steam is available immediately. In an occasional-service station, where generally steam is not available, a radial-flow double-rotation turbine can generally be started during the time required for raising the steam pressure. Such a plant may have cold boilers, or some boilers partly under pressure. As soon as the steam pressure has reached a value of about 100 lb. per sq. in. the quick-starting ejectors can pick up the vacuum, after which the turbine can be started and be ready to take over the load as soon as the boiler is capable of delivering the steam.

Lieut.-Commander R. B. Fairthorne (*communicated*): The claims of hydro-electric champions are nowadays not confined to base-load schemes, but extend to peak-load applications, of which the Galloway scheme is perhaps the most familiar to British engineers. Considerable diversity of opinion still persists even among experts as to whether the economic results of this scheme could have been bettered by thermal plant such as that described by the author, and I should welcome his opinion on the point.

The relevant figures for this scheme have been given as 102 000 kW installed and effective for 22 per cent daily load factor, costing about £30 per kW including transmission; with " all-in " cost 0·38d. per unit.

By simple equating of costs, the economic limit of capital expenditure on steam plant in competition with hydro-electric plant can be found by the formula:—

$$c = \frac{C(y + d_1 + m) - 391\,fNPX}{(y + d_2 + n)}$$

where c = expenditure (in £) on steam; C = expenditure (in £) on hydro-electric plant; d_1 = depreciation (per cent per annum) on hydro-electric plant; d_2 = depreciation (per cent per annum) on steam plant; f = coal consumption (lb.) per unit; m and n = cost of maintenance, management, etc., including all outgoings except interest, for hydro-electric and steam respectively (per cent per annum); N = price of coal (£ per ton, delivered); P = maximum demand (in kW); X = annual load factor (expressed as a fraction and referred to the maximum demand); y = rate of interest (per cent per annum).

It is the wide uncertainty of the values to be substituted for the symbols d_1, d_2, m, and n, which leads to controversy.

Mr. J. K. Hunter (*communicated*): Most of the installations to which the author refers are situated in cities or in industrial areas which are normally supplied over long transmission lines from distant hydro-electric plants, and are intended to cover the risk of interruption in the supply from these sources.

Fundamentally, the choice of the method of generation for peak-load or emergency service is governed by the necessity for supplying power to the load centre at the minimum overall cost and securing the greatest degree of reliability. Specially designed thermal plants may not necessarily offer the best solution to the problem, and it may be worth while to consider certain alternative methods which are available and which, under suitable conditions, compare not unfavourably with thermal stations of the types described by the author. These alternative methods fall under the heads of special peak-load hydro-electric plants in which the whole of the energy output is produced from the natural run-off, and pumped storage plants in which all or nearly all of the output is derived from the off-peak energy produced by interconnected thermal or run-of-river hydro-electric plants.

So far as this country is concerned, the only outstanding example of the first alternative is the Galloway hydro-electric development which was completed 2 years ago, and which has a maximum output of 103 000 kW. Whilst usually referred to as a peak-load plant it does not really fall within this category, since it operates on an annual load factor of approximately 20 per cent. The total cost of producing energy from the Galloway development has been stated to be 0·32d. per unit at the busbars, or about two-thirds of the cost of production by a modern steam plant of orthodox design.* It is no doubt true that if a steam plant were specially designed for operation at a load factor of only 20 per cent the cost would more closely approach that realized by the Galloway stations, and it would be of interest if the author could give an indication of what this figure might be under present conditions.

No major pumped-storage plants have as yet been constructed in this country, although for a number of years Continental engineers have devoted considerable and increasing attention to the matter, and upwards of 50 such plants are now in service. These for the most part derive their pumping energy from run-of-river hydro-electric plants, although there are a number which are dependent upon off-peak thermal energy. In Great Britain, where large-scale run-of-river hydro-electric plants do not and cannot exist and where on the other hand coal is relatively cheap, it might be thought that there was no scope for the pumped storage plant. I am convinced, however, that this is not the case. I had occasion recently to investigate a scheme which envisaged the construction of a major pumped-storage plant to operate at an annual load factor of the order of 2 per cent and provide peak-load service to the extent of 100 000 kW or more. The total cost of the development was estimated at a little over £6 per kW at the power station. The cost of the necessary transmission and interconnection with the industrial centres increased this figure to about £10 per kW, equivalent to between 18s. and 20s. per kW-year of peak-load service. Unfortunately, the author does not give any details of cost in connection with the thermal stations which he describes, but it is suggested that these figures compare favourably with the cost of providing similar service from specially designed thermal stations of the types covered by the paper.

---

* *Journal of the Institution of Civil Engineers*, 1938, vol. 8, pp. 323, 376, 407.

Since peak-load plants of this character are by their very nature more or less remotely situated with regard to the large cities and industrial centres, it might be argued that the necessary interconnecting transmission lines are a serious disadvantage from the point of view of reliability. Whilst this is true up to a point, it should not be forgotten that the availability of the generating equipment in a pumped storage plant is inherently much greater than that of corresponding steam equipment, and that, moreover, transmission-line outages are in general of much shorter duration than outages of steam plant.

As regards quick starting, the pumped storage plant shows up to advantage. Under suitable conditions full load can be provided from the shut-down state in about 5 minutes or even less. This can hardly be equalled by a thermal plant unless steps are taken to keep the turbines hot.

The pumped storage plant drawing its primary energy from interconnected steam stations possesses the further advantage of smoothing out the load fluctuations on the latter and thus improving the operating conditions for both boilers and turbo sets, with consequent savings in the fuel consumption. This advantage, whilst shared by plants of the steam accumulator type, is not one associated with those relying upon independent quick-steaming boilers.

So far as I am aware no survey of the potential sites for such installations has ever been attempted in this country. The report of the Water Power Resources Committee, published 20 years ago, confined itself to an investigation of the primary power which could be developed from British streams, and did not contemplate the possibilities of creating hydraulic storage plants whose function should be the provision of capacity rather than units. I would therefore suggest that when plant extensions are under consideration in this country and the merits of the several alternative methods of meeting peak-load requirements are being investigated, the possibility of a pumped hydraulic storage plant should not be entirely overlooked.

Mr. W. H. Steele (*communicated*): On large systems in this country, older plant can most economically be used for dealing with peak load. This is because there appears to be a limit in price below which it is impossible to buy plant, this limit being such that plant of reasonably good efficiency can be bought and, therefore, used, further down the load curve than the peak. The trend of ever-rising efficiency on the part of steam plant year by year, also tends towards plant being purchased and utilized in the above manner. Base-load plant need only be purchased at intervals, owing to the slow rate of increase of this type of load. A study of annual duration curves for electric supply areas in this country will bear out the above condition.

Turning to the question of dealing with peak load expeditiously, it may be said that the recurrence, magnitude, and times of peaks depend upon the class of load. A traction load has a larger number of fluctuations throughout, caused by the stopping and starting of tramcars, tubes, and trains. The load as a whole also increases and decreases, usually at known intervals throughout the 24 hours, owing to the occurrence of rush hours and comparatively quiet periods. If load fluctuations are not dealt with by the plant instantaneously the result will be wide variations of frequency, with its consequent effect on electric timekeeping. Where this is not of importance some delay may be permitted, and the load swings if not excessive may be taken by the ordinary governing capacity of the machines. It would appear that this would be satisfactory on a traction system where the recurring load-swings are of the order of 10 per cent, when the frequency variations on a load of 1 000 MW with a 6 per cent governing characteristic would be $0 \cdot 3$ cycle per sec.

With a large interconnected system, however, accurate frequency control is essential, and, with the modern tendency to install electric clocks, timekeeping assumes importance. If accurate frequency is not maintained on a system connected by interconnectors between load centres, the load on these feeders will tend to vary within limits depending upon the frequency variations. This still may not be serious when the flows are normally kept to a minimum, but where the power has to be varied at intervals to suit the requirements of economic operation a wandering frequency datum makes this operation extremely difficult and dangerous owing to the loading becoming uncontrollable, and the steps necessary to correct matters are not easily or quickly apparent when the frequency is off the normal. In this case, it is essential to have plant of special design to control load variations due to peak loads and due to weather conditions. The ideal in this respect appears to be turbine plant capable of (i) quick starting-up and (ii) dealing with a wide range of loadings. Oil-fired forced-circulation boilers with automatic equipment appears to be suitable, and if it is at all possible the plant should be controlled by automatic frequency-control equipment.

It has been the practice of a great many systems to load plant up to its economic loading or slightly above, and to take all variations up to a certain percentage on the spare running capacity up to maximum continuous rating. When this limit is exceeded, extra plant has to be run up as quickly as possible. It would be interesting to have the author's comments upon the effect on plant maintenance and economics of keeping the extra plant running at synchronous or nearly synchronous speed at times when it might be required.

Mr. T. Strand (Sweden) (*communicated*): The author mentions among other quick-steaming boilers the Forssblad boiler, of which two are installed in the Swedish State steam power plant at Västerås; a description of a different type of radiation boiler which is installed in the same station may therefore be of interest. This boiler is of considerably larger size and has been found to be more suitable for stand-by stations and to have an even shorter starting-time than the Forssblad boiler.

The boiler in question is specially designed for rapid starting, flexibility as regards load variations, and easy operation. It has a rated output of 570 000 lb. per hour when fired with pulverized coal and 660 000 lb. per hour when oil-fired, at 350 lb. per sq. in. and 800° F. The boiler was designed by the Swedish Board of Waterfalls and built by the Board's own staff. It is mainly used for stand-by and peak-load purposes, but also carries base load during low-water periods at the hydro-electric stations.

In order to facilitate quick starting and quick regulation with variations in the load, the interior of the boiler is designed for free expansion; the use of refractory furnace lining has been avoided.

Fig. A shows a cross-section of the boiler. It has a radiation furnace, and a straight vertical flue in which the superheater, economizer, and air preheater are located. Above the preheater there is an electrical ash-precipitator, and above the boiler are the air and flue-gas fans. Below the boiler are the coal mills and oil pumps. The boiler house is a tower-shaped building with a ground space of 50 ft. × 50 ft., and a total height of 170 ft. from ground-level to the top of the fan house.

The combustion space is octagonal, the walls consisting of closely set, plane tubes. It is 45 ft. high and measures 30 ft. between opposite walls. In the middle of the furnace is a circular row of vertical tubes. All the tubes hang from two drums and are also supported by springs below the water headers at the bottom of the furnace, the tubes being free to expand downwards. At the bottom of the combustion chamber is a " floor " of La Mont tubes for granulating the ash. The combustion chamber is entirely surrounded by an air duct through which passes the preheated air. The wall between the furnace and the air duct is made of flexible sheet iron, covered with a very thin layer of insulation on the side towards the furnace. The burners are placed in each of the eight corners of the furnace, and both the burner-nozzles and the air-inlet vanes are movable during operation, making it possible to change the direction of the flames so as to ensure good combustion under different load conditions.

The superheater is placed close to the furnace and is constructed so that it will produce steam at rated temperature down to one-quarter of normal full load, the regulation at higher loads being automatically controlled by injection of condensate. In order to protect the superheater under quick-starting conditions, before the boiler has started to deliver steam, the gases are cooled down to a suitable temperature by water-sprinklers in the flue below the superheater.

The economizer is built as a conventional water-tube boiler, and produces about 30 000 lb. of steam per hour at full load of the boiler.

The two air preheaters are of the regenerative Ljungström type, each with a heating surface of 107 000 sq. ft. The diameter of the rotor is 18·5 ft., and the height of the plates 5 ft.

The two air fans and the two draught fans are driven by two-speed squirrel-cage motors. Flue-gas regulation is effected by movable vanes in the inlet of the fans. All auxiliary motors and regulating devices are remote-controlled from a central control room, where the supervisory instruments are installed. One or two men can start and control the whole boiler from this control room.

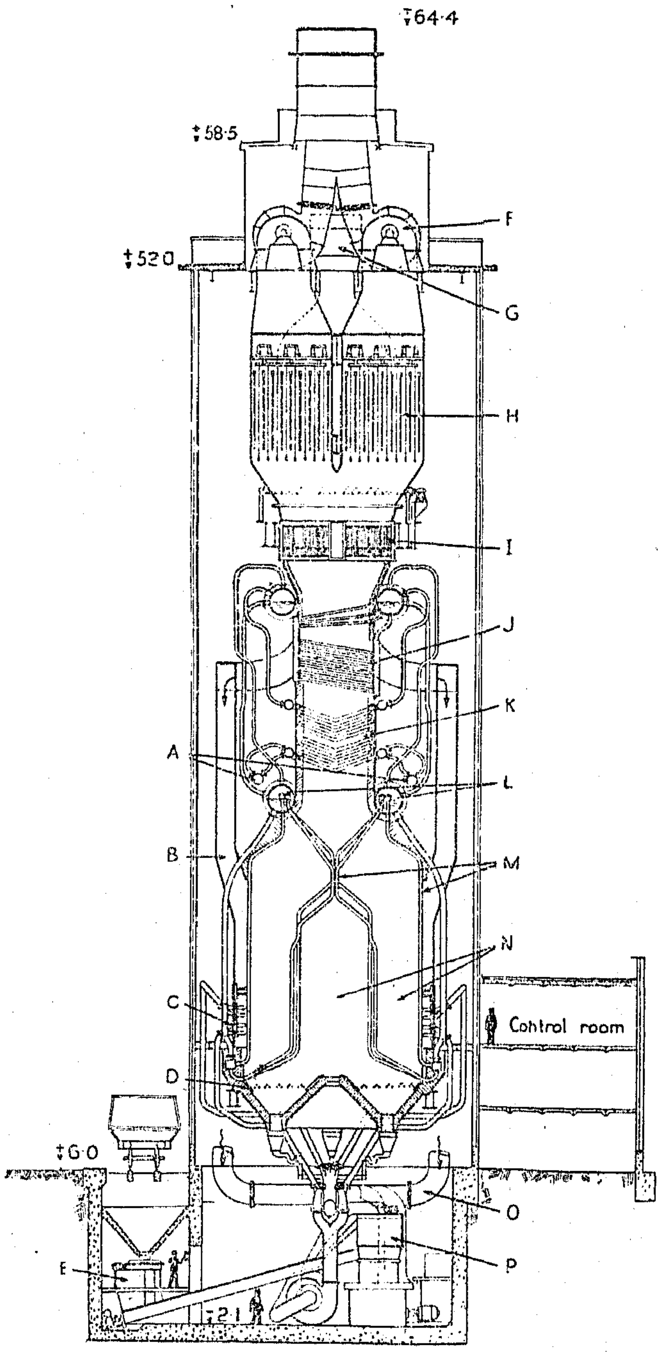


Fig. A.—Layout of quick-starting boiler at the State power station at Västerås, Sweden. Output, 660 000 lb. of steam per hour, at 350 lb. per sq. in., 800° F.

A. Outgoing steam pipelines. B. Ducts for preheated air. C. Burners for coal and oil. D. Water screen. E. Weighing machines. F. Two draught fans, each delivering 190 000 cu. ft. per min. at 370° F., 12 in. of water. G. Two air fans, each delivering 120 000 cu. ft. per min. at 70° F., 18 in. of water. H. Electrostatic ash-precipitators. I. Two air-preheaters, each of 107 000 sq. ft. heating surface. J. Economizer, 9 200 sq. ft. heating surface. K. Superheater, 9 600 sq. ft. heating surface. L. Drums, length 40 ft., diameter 5 ft. M. Tubes. N. Furnace chamber, heating surface 6 700 sq. ft., volume 28 000 cu. ft. O. For supplying preheated air to the mills. P. Two coal mills, each of 44 000 lb. per hour. Figures show heights in metres.

In the design and construction of the boiler every precaution was taken to ensure reliability of operation. Since it was first put into operation in September, 1937, the total running time has been 6 000 hours, and no maintenance work has been necessary throughout this period.

The author implies that the efficiency of the boilers is of minor importance in comparison with the capital costs of the complete station. I would point out, however, that one cannot in general leave out of consideration the influence of the running costs of the boiler, as the difference in total cost between a low- and a high-efficiency boiler depends upon the type of boiler chosen. When we were designing the boiler described above, the sizes of the various preheaters were settled by the necessity of achieving minimum yearly running costs. For different values of boiler efficiency the capital cost of each of the preheaters and fans was compared with the fuel cost and the running cost of the fans and other auxiliaries, and it was found that the most economical efficiency for this peak-load boiler was about 90 per cent at normal full load. The boiler was accordingly designed to operate at this efficiency.

The author points out that a disadvantage of most radiation-type boilers is that the efficiency is high at low loads only, and falls off appreciably at full load and overload. This effect depends, however, upon the size of the air preheater, the superheater, and the economizer. In the case of the boiler which I have mentioned all the preheaters are generously designed, and the efficiency is 90 per cent at full load, 91·5 per cent at three-quarters load, 88 per cent at half load, and about 75 per cent at quarter load.

Finally, I would draw attention to the possibility of using the steam-accumulating capacity of a boiler for dealing with peaks of short duration. The boiler described above is able during normal running to provide about 100 000 accumulated kW-min. without any increase in the amount of fuel supplied, caused by reducing the pressure. Thus the installation can deal instantaneously with rather heavy peaks. Automatic lighting and firing of the boiler facilitate the use of the steam-accumulating capacity of the boiler.

[The author's reply to this discussion will be found on page 338.]

WESTERN CENTRE, AT CARDIFF, 7TH NOVEMBER, 1938

Mr. R. W. Biles: To the long list of hazards which have to be faced in connection with maintenance of supply one further hazard could be very well added, namely the delayed delivery of new plant by the manufacturers; for it would appear that no matter how much time is allowed for the plant to be manufactured, there is in the majority of cases considerable delay in commissioning.

If the same conditions applied to-day as prevailed in pre-grid days, namely individual stations operating without interconnection, it seems to me that there would be many cases in which the supply authority would have to consider seriously the installation of emergency and peak-load plant. For instance, authorities supplying industrial consumers with power for operating continuous process plant (steel mills, paper mills, etc.) might have to consider emergency stand-by plant which could be put into commission in a matter of minutes, compared with the $\frac{3}{4}$ hour to 1 hour required to run up normal base-load plant in order to maintain supply. It is probable also that some of the supply contracts in operation to-day would not have been obtainable without such a provision or an equivalent service, calling for added capital expenditure on the part of the undertaking with the probability of not being able to supply on the advantageous terms which can be offered with the interconnected system of supply prevailing in this country.

In the S.W. England and South Wales Area of the grid, with up to 550 MW of interconnected plant, the number of occasions when assistance has been given to generating stations owing to the loss of generating plant is 40–50 per annum. There are several notable examples where the loss of 30–50 MW of plant has been taken up without noticeable effect and unbeknown to the consumers on the system in the locality of the breakdown; such emergencies demonstrate the flexibility provided by the system of running. The normal rate of pick-up in this Area over the peak period is 100–150 MW per hour; this rate applies daily between 6 a.m. and 8 a.m. as well as later on at the time of the evening peak. Such loads are easily taken care of with the existing plant, which is largely of an old pattern, without quick-starting propensities. The approximate nature of the rise of load being known beforehand, it is possible to budget for it in good time. In another area there have been many occasions when 200 MW has been picked up in 10 minutes, and as much as 350 MW in 25 minutes.

As regards the application of peak-load and emergency plant to interconnected systems, close consideration of the problem is only warranted where the existing transmission lines are fully loaded and cheap peak-load plant presents itself as an alternative to an additional transmission circuit. Such a choice would require very careful consideration, for it is possible that the loads transferred might prove to be greater at off-peak than at on-peak times.

In introducing the paper the author mentioned that the capital cost of oil-fired equipment would be £7 per kW whilst that of coal-fired plant would be £14 per kW. I might add that there is apparently no advantage in capital cost of coal-fired equipment over normal base-load plant obtainable in this country to-day. A great deal of assistance would be obtained to-day, however, if quick-starting base-load plant were available.

Mr. C. T. Allan: Confirming Mr. Biles's remarks, I know that power-station troubles that might have caused shutdowns have been avoided by the fact that the grid was always available to give assistance, and that major troubles have occurred outside the power station with switchgear, transformers, and, occasionally, feeders. It would appear, therefore, that emergency sets in this country are not very necessary.

In regard to the time of occurrence of peak loads on power stations in South Wales, we find, probably on account of the number of collieries connected, that the peak load occurs between 11 a.m. and noon.

I should like to mention that internal-combustion-engine sets may be used as an alternative to quick-starting steam sets. I recently witnessed a test of an internal-combustion engine operated by suction gas plant that started up in 4 minutes.

The paragraphs on pages 311 and 321 that refer to protection against damage by high-explosive bombs in air raids afford a prospect of power stations constructed like forts. Surely there are other ways of avoiding the enormous extra costs, and of spreading the risk.

Mr. G. H. Bowden: My remarks will be mainly directed towards public supply undertakings.

I cannot see that it would be economically sound to install special peak-load plant in central stations in this country, where a good deal of less modern, but useful, plant is available for short-period operation. The isolated private plant is in a different category, but those able to connect with a public undertaking should, in most cases, secure terms for peak-load service that would compete with the cost of special peak-load plant.

The most modern central station subdivides both its main and its auxiliary busbars, and with auxiliary alternators supplying isolated sections a total shutdown should be a very rare occurrence. In such an unlikely event a very small emergency turbo set suffices to provide supply for the auxiliaries of one boiler and a small circulating and extraction pump.

I fail to appreciate the need for special boiler plant of the flash type, for upon shutdown there is in the usual case more than enough steam available in the heat capacity of the boilers for starting a small set, in spite of its extravagant demands.

Should an air raid occur without warning, there may be a risk of escaping steam following a sudden drop in load, and consequently consideration may be warranted of means for condensing the surplus steam.

The automatic starting of auxiliary motors in the scheme described by the author, introduces the complication of separate field supply for d.c. motors; and in the case of a.c. induction machines the reduced voltage and frequency method of starting motors in a group will require careful voltage control, because of the inherent difficulty of starting and operating these motors upon supplies far removed from designed operating conditions.

Given a disciplined and well-trained operating staff, provided with complete facilities for communication and remote operation of valves, etc., there is no case for installing in British power stations the type of large emergency equipment dealt with in the paper.

Mr. G. W. Maxfield: I am glad that in introducing the paper the author dealt with the financial aspect of the installation of peak-load plant, because it is most difficult to justify such measures on an economic basis. Recently I had occasion to approach this subject with a view to establishing the relationship between capital cost, equated capital charges, use factor, and differential production cost (i.e. difference in production cost per unit between new plant and superseded plant). In this connection a nomogram was finally produced giving, for the three unknowns, the maximum price per kilowatt which could be allocated to the purchase of modern plant. I have tried to read off from the paper the figure pertaining to this emergency plant under the probable conditions, but, as expected, the figure was so low as to be "off scale." The minimum price quoted by the author is £4 per kW, and even this is too high unless it be legitimate to assume that the difference between £4 and the figure arrived at by my method could be allocable as an investment against any penalties which might be imposed on the occasion of a failure of supply.

Regarding the application of the steam accumulator, the slide showing a typical load curve is not representative of the load experienced in this part of the country. The slide shows the major peak as exceeding the morning peak by 10 %, whereas it is anticipated that this amount will be quite 25 % in this district, thus demanding a much larger accumulator.

On page 308 the author advocates the installation of an auxiliary circulating pump for reducing the auxiliary demand during starting. This is no doubt essential for the type of plant concerned, but I would support it for reasons other than those referred to. Consider a river-side plant, which, during the winter months when the load is light and the circulating water is at the temperature of melting ice, has no choice but to run at a vacuum considerably higher than that for which it was designed. In these circumstances, not only do the leaving losses exceed the regulation value, but the wetness and velocity of the exhaust steam are such that the impact of the water on the moving blades is considerably increased and erosion becomes much more vicious. If the quantity of circulating water could be reduced to the appropriate amount, either by speed regulation or by an auxiliary pump, this undesirable condition would be mitigated. Happily, owing to the interconnection of stations, the necessity of the precaution is now seldom met.

Dr. E. G. Ritchie: In this country the demand for electrical energy has developed so rapidly that whereas in 1925 the amount of reserve capacity available for peak-load and emergency work was approximately 80 per cent in terms of the maximum aggregate demand, by the end of 1937 the figure had fallen to about 20 per cent. A consideration of the most effective means of providing emergency, occasional, and regular peak-load service is therefore opportune.

So far as emergency and occasional-service stations are concerned, the present method of operating the grid seems to preclude the necessity for these; nevertheless, experience may show the desirability in certain areas of establishing independent emergency stations, and certainly war risks involve their active consideration. We are all, of course, agreed with the author that the criterion in connection with the development of stations for these special duties is low capital cost combined with maximum availability. In addition, it would seem to be desirable that such stations should link in closely with the general development and should involve the least possible departure from recognized standard practice so far as this concerns the design and nature of the equipment. In this country we are below saturation point in the usage of electrical energy, and therefore the useful life of equipment on high load factor is relatively short and likely to remain so for some considerable time. The use of obsolescent plant, or the adaptation of this, for peak-load and emergency service would therefore appear to be a sound principle for such a system as we have in this country.

The author's comments regarding the Diesel engine are interesting, and if he could give us some actual figures relating to the capital cost of this type of prime mover they would be of very great use.

He indicates as a disadvantage of the conventional Ruths thermal-storage system that the thermodynamic efficiency of the turbine is lower on accumulated steam than on live steam. This is, of course, quite true, but, as the author himself stresses, thermal efficiency in peak-load or emergency stations is not a matter of importance. Actually the heat consumption per kilowatt-hour on accumulated steam is usually about 10 per cent or 12 per cent higher than on live steam, but this only affects approximately 8 per cent of the total amount of energy generated in a station equipped with accumulators; and therefore the increase in heat consumption on this account taken over the whole of the station output amounts to something less than 1 per cent. This is unimportant in relation to the fuel savings effected by the accumulator through the elimination of peak-load firing and improvement in boiler-house load factor.

The author refers to the amount of space occupied by steam accumulators as an adverse consideration, but, in fact, steam-storage equipment is more flexible in arrangement than boiler plant. Storage equipment can be located anywhere on the site, provided the distances are not too great, and, in any case, the amount of ground space occupied is usually less than the amount of space required by the boilers the equipment displaces. I do not agree with the author's view that the capital cost of steam-storage equipment is high. Actually, under the conditions obtaining in this country, the cost of steam-storage equipment for peak-load service on a time base of $2\frac{1}{2}$ to 3 hours is less than the cost of corresponding boiler plant for the same duty with its appropriate stand-by.

In my opinion the most effective way of providing for peak-load and emergency service in this country is to install steam accumulators, utilizing existing boilers during the night or during the midday break to charge the storage system and employing existing obsolescent turbines to cover the peak loads on accumulated steam. An important possibility where new high-pressure boilers are installed and where older low-pressure turbines are available is to equip the station with steam accumulators designed for a maximum charging pressure considerably in excess of the low-pressure turbines, and to supply these with steam at their normal working pressure. By this means many high-load-factor generating stations could take over with advantage the peak loads in their own area of supply at a capital cost which compares favourably with that of any other form of peak-load plant. Stations so equipped would, throughout the greater part of the year, be capable of meeting almost instantaneously an emergency demand for power equal to the capacity of the turbines adapted to operate on accumulated steam.

So far as independent emergency stations are concerned, it is almost without doubt that, if required, they will be equipped with quick-starting boilers supplemented by steam accumulators of one form or another to provide instantaneous reserve, as described in the paper.

The author does not deal at any great length with the possibilities of feed-water storage in connection with these special stations, but this system also represents important possibilities.

[The author's reply to this discussion will be found on page 338.]

NORTH MIDLAND CENTRE, AT LEEDS, 9TH NOVEMBER, 1938

Mr. G. P. Henzell: Emergency supply can be considered separately from peak-load supply, and as regards the former we are not so badly off as, say, New Zealand. I gather that the paper is not intended to refer to Great Britain alone, because the author mentions troubles due to hurricanes and earthquakes. We are in a different situation from some other countries because of our system of interconnection, known as the "grid," which eliminates a great deal of the need for emergency quick-starting plant.

The typical load curve reproduced in Fig. 2 shows the actual peak to be of very short duration: in fact, from my own experience, I would say that it is roughly 2 hours a day for 3 months in the year. We have to think how we can save in capital cost and still meet the peak load for this comparatively short period.

It would be interesting to know the relative capacities of the low-pressure and high-pressure bridging accumulator systems. It seems to me that the low-pressure accumulator system, which needs a specially designed low-pressure turbine, is not what we want.

With regard to the author's diagram showing what happens to turbines when they are shut down, I should like to point out that this problem is probably going to grow as we adopt larger turbines and higher pressures; and some form of motor barring gear will become a necessity.

The idea of installing turbines having a fairly large overload capacity, mentioned by the author, was advocated several years ago by the late Sir Charles Parsons. There is a lot to be said for it, as it means that the turbines are always running and only require steam for an instant response. This immediate supply of steam may be obtained from a high-pressure bridging accumulator, and such a combination may meet any sudden call which is likely to occur.

Mr. W. Dundas: A study of supply-undertaking load curves shows the running hours for regular peak loads to be in the region of 200 per annum, which is less than the value stated by the author. In any case, the period is a relatively small percentage of the station running hours, which justifies the retention of some of the older plant in stations for a period in excess of the usual allotted span of 20 years. This applies particularly to the turbo-alternators, and to a lesser extent to boilers, which tend to become somewhat costly to maintain in efficient and reliable service.

Densely loaded areas with a preponderance of lighting are liable to produce sudden heavy demands on the station, due to vagaries of the weather, and in the case of d.c. supplies, storage batteries, which are available for instant service, considerably increase the flexibility in operation. With the developments of recent years, other means for handling such loads have to be considered, and the only sure alternative appears to be to maintain sufficient reserve boiler capacity and to rely on the overload capacity of the running plant. Interconnection with the grid has eased matters in that direction in this country.

The Velox boiler appears to be rather complicated, and consequently its reliability may not be as high as that of other types of boiler. Perhaps the author will give a little further explanation as to how the whole of the plant shown in Fig. 15 can be put into operation in the short time required to raise steam on the boiler, as for turbines of large capacity time and care are required in running up to speed and in picking up the load. It would appear that even with that type of plant some interruption to the supply or part of it is likely to occur, from which it is inferred that the importance attached to the maintenance of supplies is not as great in some other countries as it is in our own.

Steam storage has not made progress in this country in connection with electrical generation, although it has been adopted in certain industries. This is no doubt explained by the space required and the cost of the equipment, together with its limit of availability, and it rather looks as if the more conservative operation of boilers and plant generally provides the better solution to the problem.

Mr. J. Anderson: I should like to give some general information concerning the latest thermal-storage plant installed at the Simmering municipal power station, Vienna. The capacity of the accumulator is about 12·5 tons of steam when operating over a pressure range between 1 700 lb. per sq. in. and 500 lb. per sq. in. The accumulator has a storage capacity equivalent to 3 500 kWh, and is capable of delivering steam at the rate of more than 250 000 lb. per hour. A constant electrical load of 25 000 kW can be maintained for 8½ minutes. The duty of this accumulator is to act in case of breakdown or any emergency condition which may arise, and to bridge the time which is necessary for heating-up and placing in commission a stand-by boiler. Should a sudden failure occur on the hydro-electric system, thereby causing an excessive demand on the power station, this additional load is immediately and automatically taken by the accumulator. The accumulator plant at the Simmering station only comprises eight forged-steel drums, 49·3 in. internal diameter by 30 ft. long, the thickness of metal being 2·83 in. These drums are placed horizontally in two vertical rows, and take up very little room in relation to the duty they perform. It is sometimes suggested that the high-pressure accumulator imposes excessive work on the power-station auxiliaries owing to an increase in the steam consumption of the generating sets. It is one of the principal features of this type of accumulator, however, that it discharges steam at a constant pressure equivalent to the maximum pressure possible in the turbine plant. In the case of the Simmering installation this pressure is 500 lb. per sq. in. The accumulator is charged by passing steam from the boilers through a heat-exchanger where it gives up a portion of its superheat, which, in turn, is passed into the storage vessels. The accumulator has been in service several times since its installation, and has always responded without the slightest trace of trouble.

Regarding the Charlottenburg installation, referred to on page 319, this plant automatically takes a peak load of 40 000 kW without a single flicker in the voltage reading.

There is, to my mind, a great field for all these types of thermal storage. The maximum high-pressure bridging accumulator affords an excellent form of instantaneous emergency stand-by. The normal variable-pressure Ruths steam accumulator has its field of use in power stations as well as in connection with industrial plants, and is capable of covering such peak conditions as are experienced in many power stations in this country during the winter, or the recently developed Sunday-morning peak demand. The application of the accumulator to the electrical power supply industry in this country has not met with a great deal of encouragement, probably owing to the existence of the grid system and the elaborate arrangement of controls for dealing with peak-load conditions.

Mr. P. G. Hieatt: As far as this country is concerned, conditions generally do not warrant peak-load or emergency plant. In this connection we have to bear in mind the capital cost of peak-load plant compared with the capital cost of new generating plant. When installing peak-load plant it is necessary to look ahead, as unless an ample margin is allowed the growth of the load may necessitate new plant and boilers in, say, 2 years' time. Is it not cheaper in the end to install new turbines and new boilers than to consider peak-load plant only?

I should like some further explanation of the working of the gas turbine connected with the Velox boiler.

Mr. H. E. Midgley: Each country has its own individual peak-load problem, as is indicated by the fact that the peak-load periods in London are 9 hours and in Stockholm, Berlin, and Paris are 3 hours. Where the peak load exceeds 4 hours, boilers can be shown to be more economical as regards steam capacity than low-pressure steam accumulators.

The high-pressure accumulator is a remarkable development and has come to stay. It occupies little ground space, and has a high capacity for operating high-pressure turbines.

The Charlottenburg generating station has saved Berlin from interruptions of supply 16 times in 14 months, during one period of observation. In this period there was a complete breakdown of the overhead system. The accumulator plant at Charlottenburg occupies a good deal of space, but it did not cost a great deal.

In modern power stations, rapid running-up is not very difficult; but running down and then running up again is difficult. The Ljungström turbine, however, can be run up and down as often as one likes, without trouble, and it starts from cold in 4 minutes.

Peak-load periods do not always occur when the lighting load is on. The peak load at Leicester, for example, occurs on Sunday morning, when dinner-cooking is in progress.

Mr. W. E. Park: If we trace the development of the boiler during the last 20 years, we find that we have advanced from the original chimney-draught plant to (i) induced-draught and (ii) forced-draught plants, so adding two further auxiliaries to the original stoker motors. In more recent years we have added secondary air, and when in the near future we adopt the forced-circulation boiler we shall have in addition a motor or turbine driving the pump for circulating the water. It is obvious that the number of auxiliaries is increasing, and we have to consider not only the question of repairs and maintenance but also the degree of reliability we can expect from those auxiliaries and whether it is necessary that they should be duplicated. I should be glad to know whether the essential pumps are duplicated on the Velox boiler. It may be argued that the question of repairs and maintenance is a minor consideration because one has all the off-peak-load period in which to do repairs and maintenance. If, however, the peak is of a recurring daily character for only a short period of the year this argument is inconclusive, as one cannot very well complete major repairs in a period of 24 hours.

In the case of the Ruths high-pressure bridging accumulator I am not quite satisfied as to what happens to the excess steam which is admitted through the turbine to deal with peak loads. It seems to me that some rather awkward problems may be set up in connection with the surge tank, for instance, and the overload capabilities of the extraction pumps on the condensers. I can quite imagine that the surge tank would have to be of much larger proportions than in the ordinary case where the boiler feeds the turbine and then takes back all the condensate.

The rate of combustion which is mentioned in the paper (1 million B.Th.U. per cu. ft. per hour) is roughly 25 times the figure prevailing in normal practice in this country and in other countries for plant of standard design. For a given heat release, therefore, the volumes in the two cases are in the ratio 1/25, and as a rough guide it might be legitimate to say that the linear dimensions of the new boiler are about 1/3 those of the existing type of boiler.

Mr. R. M. Longman: Referring to the three classes of service mentioned in Table 1, the first two (emergency-service and occasional-service) are not often met with in this country, but there are places where regular peak-load plant could be installed with advantage. A number of undertakings have their power stations in business or city areas, near the load centre from which the main distribution takes place. Such sites, for reasons of health and space, may not be suitable for extensions or for accommodating base-load plant, and new stations outside the congested area are generally adopted, together with a transmission system. It may, however, be sound technically and economically to install peak-load plant in the old stations, provided this can be obtained at a low capital cost.

At present the older and less efficient low-pressure plants are being used for peak-load work; as these wear out, special consideration must be given to installing plant designed for this service.

In Ireland, Dublin appears to be a suitable place to install quick-steaming stand-by or peak-load plant in connection with the Shannon Scheme. For such plants low capital costs, simplicity in design, and reliability, are more important than economy.

In London, where some extremely rapid growths of load are occasionally experienced, there may be a good case for a quick-steaming plant, and in this connection the high-pressure bridging accumulator seems to be particularly attractive.

[The author's reply to this discussion will be found on page 338.]

NORTH-EASTERN CENTRE, AT NEWCASTLE, 14TH NOVEMBER, 1938

Mr. E. J. Edgar: The author divides plant for peak-load and emergency service into three classes, and suggests that Class (*a*) (emergency-service plants for operation upon failure of the usual supply) finds application when supply would otherwise be dependent on one or two long transmission lines, or because of vulnerability of source of supply. I presume that the term "vulnerability of source of supply" embraces generating-plant breakdown. In large-scale operation of interconnected generating stations it is this contingency which calls for the most urgent and most costly form of stand-by, particularly on systems where relatively large generating units are installed. The exception is found only in areas where heavy peaks due to fog or sudden storm clouds call for first consideration.

Provision against transmission-line outages is not nearly so important, for the reason that transmission lines to points of supply are normally in duplicate, and, in the event of outage, supply can in most cases be restored in a much shorter time than by any type of quick-starting plant. This applies particularly in the case of 132-kV lines struck by lightning.

As the author has arranged the plant in Classes (*a*), (*b*), and (*c*) in order of efficiency, and, inversely, in order of rate of starting, I would suggest that plant necessary to cater for machines out of commission for overhaul falls within Class (*c*) rather than Class (*b*). Class (*c*) provides for predetermined load schedules, and is of higher efficiency than Classes (*a*) and (*b*). It seems reasonable, therefore, to conclude that since major overhaul of plant occupies, in most cases, 8 months of the year, the plant next in order of efficiency to base-load plant should be utilized. With the foregoing in mind, I would put stand-by plant into two classes: (1) Emergency-service plant for providing against three contingencies, namely breakdown of generating plant, meeting unexpected peaks, breakdown of lines. (2) Plant to meet anticipated seasonal peaks and to cover outages of base-load plant for overhaul.

On page 306 the author states that stations of the emergency-service and occasional-service classes should be capable of starting up at short notice. I feel, however, that no matter how rapid the starting may be, it will not cater at all times for the breakdown of large generating units and enable the system frequency to be kept within safe limits. With the advent of the larger generating units, and the growing importance of maintaining normal frequency, stand-by against breakdown must of necessity be running stand-by. Furthermore, if the stand-by plant is in stations remote from the base-load plant it must, in fact, be loaded to a certain percentage of the maximum load which may be thrown on it at any instant owing to the breakdown of a large base-load unit. Nevertheless, it is appreciated that the rapidity with which stand-by plant can take up load is most important. In a group of interconnected stations the losses entailed in running relatively low-efficiency plant as stand-by to high-efficiency base-load plant are enormous, but such losses cannot be avoided entirely if the rule " economy consistent with security " is to be observed.

This may be illustrated by reference to the daily load curve (Fig. 1). Assume this is the daily load curve of a large system having the following characteristics: Peak load 500 MW, minimum load 180 MW, base-load plant 3 × 50-MW sets, remaining plant located in remote interconnected stations. To meet the minimum load, 180 MW, it would be economical but not safe to load the base-load plant to its maximum, 150 MW, and generate the remaining 30 MW at the lower-grade stations. These stations, however, have to stand-by for the breakdown of a 50-MW set, and have thus to be prepared for a maximum load of 80 MW at any instant. It has been found in practice that if frequency is to be maintained within reasonable limits, boiler plant stand-by to breakdown has to be kept alive to the extent of 50 % to 60 %, or even more, of the maximum load which it may be called upon immediately to meet. The percentage depends upon the type of lower-grade plant and the rate of response. Assuming 60 % in this case, stand-by plant would have to generate 48 MW instead of 30 MW, and the base-load plant would generate 132 MW instead of 150 MW. Without this safeguard a loss of 50 MW of plant in 180 MW would cause total collapse, and quick-starting plant would be of no avail. It will be seen that the conditions required to meet the day load of some 340 MW would be quite different, and base-load plant could operate at full output.

Dealing with plant in the second class which I have suggested, namely plant designed to meet normal anticipated peaks, etc., the chief requirement is that it should be capable of picking up load at a rate not less than that at which the load rises, otherwise a fall in frequency will occur. In cases where peaking plant is not capable of that performance (and indeed there are such cases), the remedy is to anticipate requirements by loading up peaking plant prior to the peak, reducing load on the higher-efficiency and quicker-response plant, and then using the latter to meet the peak. Here again there is considerable loss, which could be avoided by providing the right type of peaking plant.

In considering whether it would pay to install quick-response peaking plant to avoid the losses mentioned, we have to keep in mind that the base-load plant of to-day will be the lower-grade and peaking plant of a few years hence, and as more modern plant has proved itself capable of responding to load increase at a rate equal to, or greater than, the rise of load on normal supply systems, it seems reasonable to suggest that it will cater for future requirements, and special quick-response plant need not be installed.

In searching for other remedies I have formed the opinion that, before the installation of peaking plant is considered, attention should first be given to the composition of the base-load or more efficient plant. In the past, base-load stations have been regarded as properly consisting of boilers and turbines perfectly balanced in capacity. This was, no doubt, the correct combination before the principal stations were interconnected. Nowadays, however, there are many cases where excess turbo plant, particularly in base-load stations, would effect considerable economies. In explanation, I would refer again to the conditions mentioned earlier, namely a system load of 180 MW. Assuming that an additional 50-MW turbo unit is installed and that the capacity of each boiler unit is 15 MW, the four turbo units could run at 40 MW (economical rating) and generate 160 MW, leaving only 20 MW on the lower-grade plant, instead of 48 MW. The breakdown of a 50-MW unit would be met immediately by the remaining three base-load turbo units each taking up 10 MW, leaving only 10 MW to be taken up by the lower-grade stations. The breakdown of a base-load boiler unit would be met by the lower-grade stations taking up 15 MW.

Summarizing these latter remarks, the capacity of the turbo plant relative to the capacity of the boiler plant in base-load stations should be such that when the breakdown of one of the large turbo units occurs, no part of the base-load boiler plant should be rendered redundant. The cost of additional turbo plant, including buildings and switchgear, would be in the region of £5 per kW, whereas emergency stand-by plant of much lower efficiency would cost approximately £15 per kW.

Mr. W. T. Bottomley: I propose to confine my remarks to the disposition of stand-by plant in relation to the thermal-power generating systems installed in this country.

Referring to Table 1, the provision of emergency-service and occasional-service plant seems to imply that the main generating stations have sufficient capacity to meet the peak loads, but, for the various reasons stated, sufficient plant happens not to be available at the time to meet a sudden demand and this demand has to be met by the special emergency plant. In these cases the emergency plant is an extra expense, the justification for which will depend on the importance attached to the abnormal conditions that may occur. But the paper deals mainly with the regular peak-load plant placed outside the main generating stations, the justification for which appears to be the cheapness of the plant and to a certain extent the ability to start up quickly.

While I agree that it is desirable to have plant available which is capable of being started up quickly, I find it difficult to see how a modern plant of this nature can be made cheaply if it is to be placed on a site away from the main stations. The duplication of the site, civil engineering work, cooling-water system, switchgear, and buildings will more than offset the reduction in the cost per kilowatt of the turbine and boiler due to the less efficient steam cycle employed. Special stand-by plant cannot hope to be justified in this country unless it is placed on the same site as one of the existing thermal stations. But here again, the alternative to installing a special peak-load plant on an existing site with separate steaming conditions is to extend the normal base-load plant. The cost of the extension will not be much more than the cost of the peak-load plant, but the base-load extension has the advantage that it would be used for normal services, whereas the peak-load plant, if oil-fired, would not.

Apart from the question of economy, there is the other point made in favour of the special peak-load plant, namely the ability to start up quickly in emergency, and in this connection I would refer to the Velox boiler in conjunction with the built-up welded-shaft turbines illustrated in Figs. 7 and 16. The difficulties involved in using the Velox boiler in this country for peak-load purposes are the initial cost and the fact that it can only be fired with oil or gas. It is to be presumed that the problem of firing with pulverized fuel has not yet been solved, because the author does not suggest this method of firing. Regarding the initial cost, the boiler does not appear to be cheaper than an ordinary pulverized-fuel boiler, and it can hardly be classified as inexpensive stand-by plant. There is, of course, the possibility of the saving in the boiler-house building, but it is not always possible to take advantage of this if the plant is to be installed on an existing site. The main obstacle to using the Velox boiler in this country is, however, the cost of oil firing; even for peak-load operation the cost of oil firing will be found to be uneconomical. The price of oil in this country is about 3 times the price of coal for the same number of heat units, so that for every 1 per cent of the total system units per annum generated by oil firing instead of coal the total system annual fuel cost will be increased by 2 per cent.

In the typical load curve shown in Fig. 2 the peak units indicated by the shaded area amount to about 2 per cent of the total units generated. If the peak units were generated by oil firing the increase in the cost of fuel due to oil firing instead of coal firing would be 4 per cent. If this represented an average condition throughout the year the capitalized value of the increase in the fuel bill would amount to about £4 per kilowatt of peak-load plant, and it would be quite out of the question to expect a capital saving of this amount to accrue from the installation of special peak-load plant with Velox boilers.

While on this question of fuel cost I would draw attention to a point raised on page 306, where the author says that the removal of the peak load elsewhere greatly improves the load factor of the base-load plant. That may be so, but it does not improve the combined load factor of the base-load and the peak-load plants. The inference here is that the efficiency of generation of the system as a whole is improved if the peak load is placed in a separate inefficient station. But this is very improbable, because the peak load would be generated less efficiently in the peak-load station, while the efficiency of generating the unshaded portion of the load shown in Fig. 2 will not necessarily be affected by the method of generating the peak load.

The built-up welded turbine shafts illustrated in Figs. 7 and 16 imply confidence in the welded joint which I hope will be justified by experience. It is interesting to note that a turbine with this type of shaft has been in commission at Oslo since 1936, though unfortunately the duty which the turbine has to perform is not very arduous. I shall be glad if the author will tell us whether these welded shafts are considered reliable enough for large turbines operating under base-load conditions, and whether it is anticipated that base-load turbines can by this means be made quicker at starting-up than at present. It may be that the solution for peak and emergency loads in this country will be found in designing the normal base-load turbines for quicker starting and in generating the steam in pulverized-fuel boilers.

I am particularly interested in Fig. 8, showing the deformation of a steam-turbine shaft after shutting down. Since the value of the load at which the turbine is run during the test does not necessarily affect the temperature distribution along the turbine shaft, it is not clear how it can affect the amount of deformation produced after shutting down.

Mr. F. Dollin: As regards the choice of prime mover for stand-by stations, it would be interesting to know on what " use factor " the author bases his statement that oil engines are only economically advantageous in stations of less than 3 000 kW output.

The suggested steam pressures and temperatures for different types of stand-by plant given in Table 2 appear to be reasonable, although stop-valve conditions of 600 lb. per sq. in., 800° F., are perhaps on the high side for such plants. The vacuum has an equally important bearing on the design, economy, and starting characteristics of the plant, and although local conditions vary so greatly as to make it difficult to specify figures it is logical and desirable to design stand-by units for lower vacua than would be chosen for continuous-service units in similar conditions. The author refers to the higher steam consumption and corresponding increase in the cost of boilers, etc., resulting from a decrease in vacuum; against this must be set not only the saving in condenser surface and cooling-water system, but also a reduction in the size of the low-pressure end of the turbine for a given leaving loss. Apart from cost, the smaller turbine has the important advantage of better characteristics for quick starting.

In the section " Requirements affecting the turbine design," the author makes a number of statements to which I cannot subscribe, more particularly in his criticism of solid rotors, coupled with his advocacy of solid discs at the low-pressure end. It is true that, with solid rotors, calculations may show very high stresses as a result of temperature gradients in the material, but the important fact is that long experience has established that this form of rotor is capable of standing very severe treatment in service without showing any signs of trouble, such as might be expected to occur from the calculations of thermal-stress distribution. In support of this it may be interesting to mention experiences with some 18 000-kW machines with solid rotors which are required to start and stop very frequently. For demonstration purposes one of these machines was started from cold and synchronized in 3 minutes, while on another occasion a similar machine was inadvertently run up to speed from cold in less than 1 minute. It is not suggested that this is good operating practice, but the fact that such things have been done with no harm to the machines is a warning against placing too much reliance on strictly theoretical calculations. A similar warning might be uttered in connection with the author's remarks about the stresses in solid discs as compared with discs having a central hole. The doubling of the stress as a result of drilling a small hole through the centre of the disc is a theoretical result based on the assumptions of homogeneity and strictly elastic behaviour of the material. Apart from the fact that the material at the centre is likely to be of inferior quality as compared with the material farther away from the centre, it may be remarked that the factor of safety is usually specified in relation to the average stress rather than the elastic stress at the bore. In passing, it may be mentioned that in Fig. 7 the author shows a turbine where the largest disc, namely the impulse wheel, has a hole through the centre while the smaller disc at the low-pressure end has not.

As regards methods of reducing the starting time of steam turbines, I do not agree with his statement that the use of a turning gear necessitates a continuously-running high-pressure pump. Messrs. C. A. Parsons have a large number of turning gears in use with several years' service behind them, and in no case is a high-pressure oil pump kept running continuously. In some cases no high-pressure oil pump is supplied at all, the turning-gear drive having enough power to start the turbine rotor and keep it moving with a journal surface speed in the region of 1 ft. per sec. With very heavy turbine rotors a high-pressure oil system is often provided for the purpose of reducing the starting torque and enabling the size of the turbine-gear motor to be kept reasonably small, but as soon as the turbine rotor is started the high-pressure oil pump is shut down. There are a number of large American machines which have a turning speed of about 0·1 ft. per sec. at the journal surface and are not provided with high-pressure oiling. It is reported that the bearing surfaces show no damage as a result of this operation, the chief objection to it apparently being that a very long train of gearing is required to give sufficient mechanical advantage to provide the necessary high torque.

One very desirable feature in any turbine, and particularly in a machine intended for quick starting, which the author does not mention is the provision of some means of increasing the clearances during starting and at other times when the pressure and temperature distributions are changing rapidly. If there is no means of adjusting the clearances they must be made large enough to accommodate the temporary distortions that will occur at such times. Adjustment of the clearances while the turbine is running is obtained in Parsons turbines by arranging the clearances in an axial direction and fitting a gear which enables the thrust block to be moved axially at will. I should like to refer in particular to a single-cylinder 15 000-kW 3 000-r.p.m. turbine for a stand-by station, designed for a normal starting time of 5 minutes, which has proved itself entirely satisfactory in meeting this condition in service. Special features of the design are the shortness and robust construction of the machine, the absence of any " concertina " formation in the cylinder, the use of a hollow spindle (not from any apprehension as to thermal stresses in the rotor, but in order to obtain equal rates of heating and cooling for spindle and cylinder), and the provision of a thrust-adjusting gear for the purpose already mentioned. This unit is installed in the Evans Bay power station of the City of Wellington, New Zealand, and receives steam from the two Velox boilers mentioned by the author.

Mr. G. R. Peterson: The three classes of stand-by plants defined on page 305 might usefully be reduced to the two mentioned in the title of the paper, namely plants for peak-load service and plants for emergency service. In his description of the types of stand-by plants suitable for providing a reserve source of power the author does not refer to the alternative which has been adopted in this country, namely the interconnection of power stations by means of a high-voltage transmission system.

The main causes of supply failures in this country are, firstly, generating-plant breakdowns which the author does not mention) and, secondly, transmission-line breakdowns, which are most frequently caused by lightning discharges. The interconnection of power stations ensures that the breakdown of even the largest generating set will not affect the supply to consumers, since the other power stations can be called upon to make good the deficiency caused by the breakdown. Complete failure of the transmission line to an important town is, of course, a very infrequent occurrence, and in any case most of the principal towns in England still have a generating station capable of supplying at least the essential part of the local load. It is obviously probable that this condition will persist in the future, since, other things being equal, it is preferable to locate generating stations at the centre of dense load areas. Moreover, the provision of emergency plant to cover transmission-line failure would be of very little use, since in nearly all cases the transmission line could be put back into commission very much more quickly than the emergency plant could be brought on load.

There is no doubt that a transmission line is very much more secure against risk of damage by hurricanes, floods, earthquakes, riots, and bombardments, than any generating station, since, if a generating station is destroyed it may be months or even years before the damage can be repaired, whereas damage to transmission equipment can generally be repaired in a few hours. I think, therefore, that the policy adopted in this country of interconnecting power stations by transmission lines affords a far higher degree of security than would be provided by a large number of emergency-service plants.

While I am in agreement with the author that specially-designed quick-response peak-load stations are desirable, it is very difficult to justify their installation economically when plant extensions are under consideration. The reason for this is that there is always the alternative proposal of replacing existing base-load plant by more efficient base-load plant and using the displaced base-load plant for peak-load purposes. If, for example, it is assumed that the cost of base-load plant is £3 per kilowatt more than the cost of peak-load plant, and capital charges are taken at the rate of $8\frac{1}{2}$ per cent, then the annual capital cost per kilowatt of the base-load plant will be 61·2d. more than the annual capital cost of the peak-load plant. To justify this extra cost it must be shown that it will be more than offset by the saving in fuel cost of the proposed new base-load plant as compared with the existing old base-load plant. If one assumes 70 per cent load factor for the base-load plant, then each kilowatt will produce roughly 6 120 units per annum, and it is thus obvious that in order that the proposed new base-load plant may be economically the equal of new peak-load plant it must be capable of producing energy at 0·01d. per unit less than the existing base-load plant. This figure of 0·01d. may be roughly taken as representing 5 per cent increase in thermal efficiency (e.g. from 20 per cent thermal efficiency to 21 per cent thermal efficiency). Owing to the rapid improvement in the design of plant in the past it has, in almost every case, been possible to design a new station whose thermal efficiency would be very much more than 5 per cent greater than that of the existing plant, and for this reason the installation of special peak-load plant has been economically impossible. As the rate of improvement in design of base-load plant slows down, however, it will eventually become economically possible to make installations of special plant for peak-load purposes.

Referring now to the use of oil fuel, on page 307 the author states that for European conditions the critical plant use-factor for which the cost of using oil fuel is more or less equal to that of using coal fuel lies between 7 per cent and 10 per cent. The cost of heat derived from oil fuel in this country is about 3 times the cost of heat derived from coal. Thus a 10-MW peak-load set with 5 per cent plant use-factor would generate 4·38 million kWh per annum, which, with coal at £1 per ton, and assuming a fuel consumption of 2 lb. per unit generated, would cost about £3 900. With oil fuel the same output would cost £11 700 or £7 800 more. This is obviously far more than the extra cost of fuel handling, coal storage, etc., and in fact it appears that the critical value of use-factor referred to by the author is probably less than 1 per cent for British conditions.

Finally, I should like to refer briefly to the load curves shown in Figs. 1 and 2. That shown in Fig. 1, which indicates an evening peak nearly 50 per cent in excess of the morning peak, is, I feel, a rather abnormal condition for this country. Owing to the increased use of electricity for all purposes the load curve of the average undertaking has gradually become flattened. In this area, for example, the afternoon peak is only some 10 per cent or 15 per cent higher than the morning peak. The text of the paper rather implies that the duration curve shown in Fig. 2 is derived from the load curves for the whole year, but I think it actually applies to the particular day shown in Fig. 1. In considering the output to be taken from the peak-load plant, I do not think that it is quite justifiable to neglect the variation in plant availability throughout the year, because experience has shown that major overhauls of the base-load plant during the summer frequently render it necessary to run certain peak-load plant during the summer months as well as during the winter months. It is necessary to consider not only the load duration curve but also what I might describe as the plant availability curve.

Mr. M. G. S. Swallow: I should like to draw attention to the fact that the author's firm has recently received an order for a power station of the bomb-proof type to accommodate a generating unit of 4 000 kW, but in this case the turbo-alternator is driven by a gas turbine. This type of drive is particularly suited to such a purpose, as the unit occupies a small amount of space, the first cost is low, and no water supply is required for condensing purposes. The gas turbine is of the constant-pressure type driving a compressor which supplies the compressed air to a combustion chamber, the fuel used being oil. By supplying the necessary excess amount of air, the temperature of the gases is kept reduced to that suitable for operation in a gas turbine. From the combustion chamber the gases pass through the gas turbine, from which they escape to atmosphere. As no chimney for producing a draught is required, the exhaust gases can be taken out in the manner most suited to the arrangement of the station. This type of turbine has been used for many years in the Velox steam generator, and also as power-producing plant in supercharging and chemical processes, where the electrical energy is produced as a by-product.

The technical possibility of building turbines of this description depends upon the temperature which the blading material is able to stand, the efficiency of the blower supplying the compressed air for combustion, and the efficiency of the gas turbine itself. With the materials at present available, the gas temperature must not exceed 1 000° F., and this temperature determines the quantity of air which it is necessary to supply in order to ensure combustion. It amounts to 3–4 times the quantity of air required for actual combustion.

With axial-flow compressors designed on the basis of the results obtained through aerodynamic research, efficiencies of 70 per cent and above can be obtained. Such compressors have been in use for some years with the Velox boiler, and have been so far perfected that for a plant such as the one referred to above an overall efficiency of the gas turbine and compressor of approximately 75 per cent can be obtained. This enables an overall efficiency (referred to alternator terminals) of 17 per cent to be reached. In a plant which has to operate for longer periods than a simple emergency station, the efficiency can be raised to 25 per cent by employing an air heater in which the compressed air is preheated by the turbine exhaust gases.

Whilst the gas turbine requires no feed-water pump or condensing plant, it has to be provided with a small auxiliary oil-engine-driven generator for driving the starting motor in the event of the outside current failing.

The fact that oil fuel is used limits the use of this type of plant, the cost of oil as compared with coal being in the ratio of 3 to 1. The author's firm, I understand, is pursuing its experiments with powdered fuel with considerable promise of success. With powdered fuel and a possible overall efficiency of 25 per cent, the gas turbine would therefore become a definite technical possibility for a much wider field than the emergency power station, which appears at present to be its limit in this country.

Mr. V. A. H. Clements: In his enumeration of the advantages of the plant he describes, the author appears to lose sight of the chief point of interest to the supply industry in this country, namely its potential use as very cheap plant solely for peak-load purposes. Up to the present it has been possible to make use of inefficient plant for peak-load purposes as and when it has been superseded by efficient plant, but this condition cannot continue much longer. It is difficult to visualize power-station efficiency improving very much further, and, as a consequence, it is probable that the rate of obsolescence of plant will decrease: on the other hand, the percentage which the peak load is of the total load will probably remain at least the same and may even increase, presaging a larger amount of peak load to be dealt with as the industry expands. Thus the time will arrive when new plant has to be installed which could not be justified on the grounds of improved efficiency compared with the old, and must therefore be justified only by the existence of the peak.

On referring to Fig. 2, a rough calculation will show that the units in a peak of 10 per cent are supplied at about 0·5 per cent load factor. With the cost of plant at £2 per annum per kilowatt sent out, the costs of these units in capital charges alone are therefore of the order of 1s. per unit, to which of course many additions have to be made before the economical selling price can be arrived at. It is, however, apparent that the industry cannot face an increasing peak being dealt with by new plant unless the new plant is installed at very much lower capital costs than obtain at present. I calculate that, if it could be installed at about £10 per kilowatt sent out, or, say, 16s. per annum per kW sent out, about 60 per cent—or some 8d.—of the charges would be saved.

Power-station designers and those responsible for the selling of energy will have to give a very considerable amount of thought to future policy, as since it is obvious that unless capital costs for dealing with the peak can be minimized it will be impossible to supply low-load-factor energy, used at times of peak, at the present low level of charges.

Mr. R. W. Gregory: The author rather neglects the possibility of employing coal gas as a fuel for off-peak plants. Coal gas is indigenous to this country, and is far less likely to "run dry" than oil, which, according to some authorities, has only a life of about 20 years. In this district too, coal gas as a fuel can be purchased from the public utilities companies much more cheaply than oil, and, although it might ultimately be shown that special plants for off-peak purposes are not economical, yet I feel that some consideration might be given to the possibility of comparatively small gas-engine stations located at strategic points on the distribution networks, as distinct from the transmission networks, to deal with the winter peaks and for use in emergencies.

Ricardo some years ago suggested that the cheapest form of power from internal-combustion engines could be obtained by using a battery of standard motor-bus engines, as for such engines the power/weight factor was high and the cost low. A peak-load generating station containing such a plant and using gas as a fuel could, in these days, be practically automatic in its operation.

A short time ago I read in an American paper that a large power corporation had erected an experimental coke-oven plant in which heat was supplied electrically to the retort. Considerable advantages were claimed for this plant over the normal ovens, and it was suggested that such a plant would provide a very fine off-peak load to the generating station. It would allow coke and gas to be made at night, the gas being stored and used in gas engines or gas turbines during the electrical peak period. I have not heard whether this electrical coke-oven plant is a commercial success, but if it ever is it will open up a wonderful vista of co-operation between the great public utilities, gas and electricity.

THE AUTHOR'S REPLY TO THE DISCUSSIONS AT LONDON, CARDIFF, LEEDS, AND NEWCASTLE

Mr. H. S. Hvistendahl (*in reply*): Mr. Johnstone Wright has mentioned; and many other speakers have also expressed the opinion, that there is little likelihood of a large demand in Great Britain for power plants specially designed for emergency-service duty. I agree that under normal peace-time conditions pure emergency-service stations, i.e. stations which are called upon for service solely in the event of a complete black-out, are justified in Great Britain only in rare cases where an interruption of a few hours would mean considerable material loss, or might involve danger to human life. The high degree of security normally afforded by the British grid, as shown by the statements of Messrs. Allan, Biles, and Henzell, and the fact—pointed out by Mr. Selvey—that in England the bulk of the units generated are not transmitted but are consumed locally, has resulted in the almost complete elimination of serious black-outs at home, but there are many instances in the Dominions and in other countries, where conditions render the provision of special emergency-service stations desirable. This also applies to plants of the occasional-service group.

Messrs. Edgar and Petersen suggest that the number of classes shown in Table 1 be reduced to two. Some stand-by steam plants operating in conjunction with hydro-electric systems might be looked upon as peak-load units, but others, which may be required to run continuously for several weeks at maximum economical load until an adequate reserve of water has again collected behind the dams, cannot be classified in either the first or the last groups. Clearly any available stand-by will be made use of when the necessity arises, whatever may be the cause of the deficiency, but the need of catering for one particular set of conditions more than any other will be the deciding factor determining the construction of the station, which should accordingly be designed with special regard for the most frequent eventuality. For this reason I think the distinction between the proposed three classes should be retained and the first group limited to stations intended for replacing the usual supply with minimum delay upon the occurrence of a complete black-out. This group might also include plants intended for supplying the requirements of defence works in time of war.

It was not intended to advocate the construction of special stand-by plants as a normal reserve for outage of individual turbo-sets. I agree with Messrs. Johnstone Wright, Edgar, and Petersen, that security should be sought first and foremost by sub-division of the generating capacity and by operating the units in such a manner that the sudden outage of the largest set can be made good by the combined overload capacity of the other units already running in the same station, thus preventing the redundancy of boiler capacity referred to by Mr. Edgar; and that it should be sought in the second place, where feasible and economical, by interconnection and sub-division of the lines.

Obsolete base-load plants may continue to be usefully employed as occasional-service or peak-load plants, but they cannot be considered suitable for emergency service if, as is generally the case, 4 to 5 hours are required to start them from the "dead" and cold state.

Many speakers have voiced the opinion that new plant should be of the base-load type, and that the peak load should be carried by the displaced older base-load equipment; this because the capitalized value of the saving due to the difference between the efficiencies of the new and the existing base-load plants makes the installation of the former, and the consequent release of the latter for peak-load duty, more economical than the construction of a low-cost new peak-load station. Mr. Blackburn illustrates this point by means of an example where 100 000 kW of modern base-load plant generating 600 million units yearly would result in a saving of £100 000 per annum, or of 0·04d. per kWh. This is equivalent, for average English conditions, to a reduction of the coal bill of 30 to 40 %, and I agree with Messrs. Blackburn, Bottomley, Bowden, Burge, Hieatt, Selvey, and Steele, that in such instances where existing equipment is due for modernization new base-load and not peak-load plant is justified. Mr. Maxfield's nomogram must make some allowance for capitalized saving of this nature, as the result which it gives cannot otherwise be accounted for.

Since the creation of the Central Electricity Board, the average thermal efficiency of British power stations has been nearly trebled, but, as pointed out by Messrs. Clements and Steele, the possibilities of further improvement are such that only relatively small gains may be expected in the future. In other words, thermal efficiencies of base-load steam plant are approaching a limit, and savings of the order of that cited by Mr. Blackburn will soon be possible no longer. New, low-cost, peak-load plant, either separate or, as suggested by Mr. Longmann, located in existing stations, will then deserve earnest consideration, especially in such cases as those mentioned by Mr. Biles, where transmission and distribution systems are already loaded to capacity.

Messrs. Bottomley and Petersen are doubtful whether, under the conditions prevailing in Great Britain, oil firing will show any economy, even for stand-by stations with a low plant-use factor. Whilst preference will naturally be given to a home-produced fuel, the duty of the engineer is to achieve a given result at minimum cost. An oil-fired stand-by plant can be built considerably cheaper than a coal-fired one, especially when the conventional layout of a coal-fired station with its separate boiler house, turbine room, and feed-pump bay, is abandoned in favour of a compact unit system of boiler, generating set, and auxiliaries. The total costs of generation can be divided into two parts, the approximately constant part c, consisting largely of capital charges, and the variable part mx, approximately proportional to the number of units generated x.

If the suffixes 1 and 2 denote the cost constants for coal and oil fuel respectively, then the yearly output of units at which parity is obtained is given by the relation

$$m_1x + c_1 = m_2x + c_2$$

or

$$x = \frac{c_1 - c_2}{m_2 - m_1}$$

If the yearly output of units is substantially lower than this critical value, the oil-fired plant is clearly the more economical proposition. Mr. Petersen's comparison overlooks the fact that, for intermittent service of short duration, the firing efficiency with oil fuel, owing to the absence of banking losses and to the small losses at starting and stopping, is very much higher than that obtained with coal firing.

Lieut.-Commander Fairthorne asks whether stand-by steam plants would have been cheaper than the Galloway scheme. Whilst I believe that, for a 22 % use-factor, coal-fired peak-load steam plant would have shown a lower cost per unit, the permanency of the investment, the advantage of quick availability, and the many local benefits, cause me to consider the Galloway scheme to be a thoroughly sound and justifiable enterprise.

Mr. J. K. Hunter's question as to what would have been the actual cost per unit of the equivalent thermal peak-load plant, I fear I cannot answer without making a detailed study of the case, but I estimate that a figure of $\frac{1}{4}$d. per kWh might have been attained.

Pumped storage plants should be considered when the energy accumulated is derived from run-of-river low-head stations, but owing to their low overall efficiency, of the order of 65 %, I think that only in exceptional cases will they prove to be economical in conjunction with steam plants, although they may be justified by other considerations.

Mr. Steele suggests that automatic oil-fired plants be employed to assist in controlling the frequency. This application may in certain instances be of considerable value. In reply to his question regarding the cost of running stand-by equipment idle, this can be estimated from the fixed charges, and the cost of idle running power which is equivalent to about 5–8 % of the full-load variable charges.

Messrs. Bowden and Burge consider the variable-voltage and variable-frequency methods of starting the station auxiliaries, suggested in the paper, to be complicated and unreliable. I do not agree with this point of view, as the alternative of individual starters involves a multiplicity of switching components, control circuits with auxiliary contacts, etc., offering more possibilities of a failure than a pair of common transfer switches. At starting there is no difficulty in supplying the small energy requirements of the fields by means either of the battery or of the exciter of the diesel-driven starting set. The field connections were omitted from the diagrams in order that the fundamental principle might be seen at a glance. I agree with Mr. Maxfield that a subdivision of the circulating-water pump capacity has the additional advantage that, by cutting out one pump, unnecessary blade erosion may be prevented when the vacuum cannot be fully utilized by the turbine, but I do not see how the blade-erosion problem is automatically solved by interconnection.

Messrs. Bottomley, Burge, and Dollin, appear doubtful of the reliability of turbines with fabricated rotors. The welded design of rotor was developed 10 years ago to overcome the difficulty of obtaining large forgings free from flaws. Adequate precautions during manufacture ensure the soundness of each layer of metal deposited; moreover, the factor of safety in the welds is of the order of 100, and, as mentioned in the paper, all stresses are relieved by a final annealing of the complete rotor. The first machines with fabricated rotors have now been running 9 years, and the very satisfactory experience with this design has led to its general adoption by the author's firm for all but the smallest sizes of turbines.

Mr. Burge states that English forge-masters can supply entirely reliable forgings up to 36 in. diameter, and recommends the use of solid rotors without an inspection bore-hole, to reduce hub stressing, but I do not think there can be many turbine manufacturers prepared to risk their reputation by taking for granted that the innermost, and incidentally the most highly stressed, part of long forgings of this diameter is perfectly sound and free from flaws. Fabricated rotors, on the other hand, do allow proper inspection and testing of all components, and I feel sure that this construction will in due course completely displace the large forging.

Concerning the reduction in turbine cost obtainable by designing it for a poor vacuum, I agree that some gain is achievable in this direction, but I would draw the attention of Messrs. Burge and Dollin to the fact, pointed out in the paper, that the part of the heat drop produced at the least cost is that in the vacuum region, and that a reduction in the turbine efficiency means an increase in the size of the boiler and of other components.

The impulse disc in Fig. 7 is provided with a hole, but because of the very short impulse blades the maximum stress in this wheel is quite low, i.e. less than that of the solid last low-pressure disc, so that the inconsistency referred to by Mr. Dollin is only apparent. I am much interested in his remarks on turning gears, but whilst I agree that a high-pressure pump is unnecessary with a journal speed of 1 ft. per sec., the power required to run at this speed is greater than the combined requirements of high-pressure pump and turning gear for a speed of, say, 0·1 ft. per sec. The reported satisfactory operation of large American machines at low turning speeds without high-pressure oil pump does not quite tally with that of the author's firm, which has shown that where machines are shut down daily the amount of bearing wear is inadmissibly high.

In reply to Mr. Bottomley's query, the magnitude of the shaft deformation after shutting down depends on the load at which the turbine has been running, because with decreasing load the pressure drop tends to become concentrated over the first few stages, and the greater part of the turbine is under vacuum and therefore cool. With large machines and a poor vacuum a reversal of this effect may take place at light load, because the windage losses of the long low-pressure blades may cause a rise in temperature towards the exhaust end of the rotor.

In reply to Mr. Metz, the thermo-dynamic efficiency of the turbine for stand-by service illustrated in the paper is only 2–3 % lower than that of base-load machines of the same size. The figure of 90·3 % quoted by him and Mr. Lönnegren is not directly comparable with those usually cited in test reports relating to other designs, because it does not include the inlet and governing-valve losses. Morever, it appears to have been measured under abnormal vacuum conditions.* The inlet temperature of the cooling water, which might have explained why such a bad vacuum was recorded for this point with only 60 % load, is unfortunately omitted from the Table.

I am much indebted to Mr. Strand for his contribution describing the 660 000 lb.-per-hour boiler designed and built by the Swedish Board of Waterfalls. It is interesting to compare the space requirements of this boiler (about 0·87 cubic ft. per lb. of steam) with those of the Velox units at Oslo (about 0·33 cubic ft. per lb. of steam). I have also tried to check the efficiencies quoted in the text from the data published in the legend of Fig. A, but had to abandon the attempt, as the value of the radiation losses arrived at was much smaller than could be expected, even for a special boiler of this type. Steam-accumulation capacity in a boiler for stand-by service is not an unmixed blessing, as it means correspondingly high losses on shutting down.

Mr. Burge appears to entertain fears about the gas turbine of the Velox boiler. These are quite unnecessary, as the gas turbine, which can be looked upon as a windmill located in the path of the gases between the boiler and the economizer, is really much simpler than, for instance, a steam turbine; whilst the compressor which it drives is at least as reliable as the forced and induced draught fan units of the usual boiler.

Referring to Mr. Hieatt's query, the principle of the Velox boiler is perhaps most clearly understood by considering it not as a boiler but as an internal-combustion engine, in which only a fraction of the heat input, enough to supply the energy required for compressing the combustion air, develops power, the remainder being abstracted by the cooling water for steam generation.

In reply to Mr. Metz, the efficiencies given in Fig. 11 include all auxiliaries except the feed pumps, and the time taken on the occasion of the acceptance tests on site for starting the Wellington station from cold until power was delivered was 12½ minutes, of which 4½ minutes were required for the boilers.

In reply to Mr. Park, it has not been found necessary or desirable to duplicate the auxiliaries of the Velox boiler.

---

* See *Engineering*, 1934, vol. 138, p. 57.

Replying to Mr. Dundas's query, the Oslo station is intended essentially for helping out the hydro-electric supply during periods of water shortage, under which conditions the starting time of about 20 minutes is fast enough. There are many instances of Velox plants where load-swings of the order of 50 % of the full-load rating have been taken practically instantaneously, without any trouble being experienced with either the boiler or the turbine.

The contributions of Messrs. Anderson and Midgley, and Dr. Ritchie, are welcome additions to the necessarily condensed treatment of the accumulator question in the paper, but I still think that for energy-storage purposes only the high-pressure accumulator is likely to be used to any appreciable extent in the future. There may be quite a field for the application suggested by Mr. Henzell of a high-pressure accumulator with a turbine of large overload capacity.

Mr. Gregory considers that I have neglected the possibilities of coal gas as a fuel for stand-by stations, but whilst I agree that there may be a field for small stand-by plants running on producer gas, for the reasons expressed in the paper I believe that gas fuel is unlikely to be used to any considerable extent by large stations.

The combustion gas-turbine referred to by Dr. Meyer and Mr. Swallow appears to be particularly well suited for emergency-service plants of medium size, i.e. of the order of 2 000–8 000 kW, but I think that several years will elapse before it will be able to compete with large steam plants, even when the use-factor is low.

Considering the question of costs, instability of currencies and varying protective tariffs of different countries make it exceedingly difficult to give the figures or to establish the comparisons which have been requested by so many of the speakers. Mr. Metz gives figures for Swedish conditions, and I consider these to be well representative of the averages which may be expected for oil-fired stand-by plants where open competition is invited. Taking British conditions, where the cost of base-load stations varies between £14–20 per kW, I anticipate the corresponding cost of simple stand-by plant of 20 000–50 000 kW output to lie between £9 and £12 per kW for coal firing, and between £6 and £9 for oil firing.

POWER STATIONS AND THEIR EQUIPMENT*

By Sir LEONARD PEARCE, C.B.E., D.Sc., Member.†

CONTENTS

(1) Electricity Supply and Performance.
  (*a*) Increase in output of electricity.
  (*b*) Increase in maximum demand.
  (*c*) Installed plant capacity.
  (*d*) Thermal efficiency.

(2) Steam Conditions.

(3) Turbine Plants and Auxiliaries.
  (*a*) Size of units.
  (*b*) Speeds.
  (*c*) Type.
  (*d*) Blading.
  (*e*) Condensers.
  (*f*) Feed-water heaters.
  (*g*) Auxiliaries.

(4) Boiler Plants.
  (*a*) Size of units.
  (*b*) Rating.
  (*c*) Relationship between boiler and turbine plant capacity.
  (*d*) Water walls and boiler heating surface.
  (*e*) Combustion chambers.
  (*f*) Firing.

(5) Special Designs of Boilers.
  (*a*) Once-through boilers, such as the Benson, Sulzer, and Ramsin.
  (*b*) Forced-water-circulation boilers, such as the La Mont and Velox.

CONTENTS—*continued.*

  (*c*) Forced-steam-circulation boilers, such as the Loeffler.
  Examples in this country.

(6) Materials and Construction.
  (*a*) Materials.
  (*b*) High-pressure and high-temperature steam pipework.

(7) Electrical Equipment.
  (*a*) Alternators.
  (*b*) Transformers.
  (*c*) Switchgear.

(8) Hydro-electric Plants.

(9) Fire and Air-raid Precautions.

(10) General.

(1) ELECTRICITY SUPPLY AND PERFORMANCE

(a) Increase in Output of Electricity

The generation of electricity in this country continues to increase steadily, as may be seen from Table 1, which shows the total units generated during the last four years and during the year ended 31st March, 1928. It will be seen that in recent years the annual increase has been at a rate of about 12–14 %, and that over the last 3 years the total increase is about 44 %. In the 10-year period this increase has reached the very high figure of about 144 %.

In Table 2 figures are given for the total increase in

Table 1

Generation of Electricity in Great Britain

(From *Electricity Commissioners' Fuel Returns*)

Units Generated

Year	Units generated	Increase over previous year	
	kWh	kWh	%
Ending 31st March, 1928	9 927 850 630	—	—
Ending 31st December, 1934	16 895 551 396	—	—
Ending 31st December, 1935	18 993 474 436	2 097 923 040	12·4
Ending 31st December, 1936	21 649 693 157	2 656 218 721	13·98
Ending 31st December, 1937	24 314 845 292	2 665 152 135	12·31
Total increase over 3 years		7 419 293 896	43·9
Total increase over 10 years (approximate)		14 386 994 662	143·9

---

* A review of progress.

† London Power Company, Ltd.

Table 2

INCREASE IN OUTPUT OF ELECTRICITY IN VARIOUS COUNTRIES DURING THE PAST THREE YEARS

Year	United States			Germany			Canada			France			Italy		
	Output	Increase over previous year		Output	Increase over previous year		Output	Increase over previous year		Output	Increase over previous year		Output	Increase over previous year	
	kWh × 10^6	kWh × 10^6	%	kWh × 10^6	kWh × 10^6	%	kWh × 10^6	kWh × 10^6	%	kWh × 10^6	kWh × 10^6	%	kWh × 10^6	kWh × 10^6	%
1934	84 986	—	—	30 661	—	—	21 197	—	—	15 172	—	—	11 884	—	—
1935	92 612	7 626	8·9	35 699	5 038	16·4	23 283	2 086	9·8	15 818	646	4·2	13 118	1 234	10·3
1936	106 566	13 954	15·1	41 326	5 627	15·7	25 394	2 101	9·0	16 659	841	5·3	13 563	445	3·4
1937	114 200	7 634	7·1	49 013	7 687	18·6	27 575	2 181	8·5	18 292	1 633	9·8	14 961	1 398	10·3
Increase over 3 years	—	29 214	34·3	—	18 352	59·8	—	6 378	30·0	—	3 120	20·5	—	3 077	25·8

generation of electricity in various other countries, and it will be noticed that, with the exception of Germany, this increase has been at a lower rate than in this country.

(b) Increase in Maximum Demand

Over the same periods there has been an increase in the maximum demand on generating stations and this is illustrated by the figures given in Table 3, which, however, is based on slightly different time periods. This shows that during the last 3 years the increase has been at the rate of about 11 % per annum, totalling 37·6 % for the 3-year period. For the 10-year period the figure is 104·3 %.

Table 3

MAXIMUM DEMAND

Year. [Period:—For companies up to 31st Dec. of first-mentioned year, for authorities up to 31st March (or 15th May) of last year]	Maximum demand	
	Generating stations	Increase over previous year
	kW	%
1927–1928	3 235 188	—
1933–1934	4 802 302	—
1934–1935	5 297 462	10·3
1935–1936	6 044 011	14·1
1936–1937	6 609 132	9·4
Total increase over 3 years	1 806 830	37·6
Total increase over 10 years	3 373 944	104·3

(c) Installed Plant Capacity

To accommodate the maximum demands it has been necessary to install additional plant, and this is illustrated in Table 4, which refers to stations owned by companies and public authorities and shows the new plant installed, plant taken out of commission, and the corresponding net increase.

It will be clear from Table 5 that the major portion of the new plant has been installed in generating stations "selected" in accordance with the provisions of the Electricity (Supply) Act, 1926.

It will also be noticed that the installed plant capacity has not increased at anything like the same rate as the total consumption and maximum demand, as shown in Tables 1 and 3, owing to the interconnection which has been established between the various stations by the grid, whereby it is unnecessary to provide the same margin in total standby capacity as was necessary some years ago when each station or undertaking was a separate entity.

(d) Thermal Efficiencies

The thermal efficiency of steam generating stations in this country has continued to improve steadily as a result of the adoption of more efficient heat cycles, and the bulk generation of electricity in large base-load power

Table 4

VARIATIONS IN INSTALLED PLANT CAPACITY IN STATIONS OF COMPANIES AND PUBLIC AUTHORITIES

(From *Electricity Commissioners' Returns*)

Year. [Period:—For companies up to 31st Dec. of first-mentioned year, for authorities up to 31st March (or 15th May) of last-mentioned year]	Number of stations	Total installed capacity	Capacity of plant placed in commission during the year	Capacity of plant taken out of commission during the year	Net increased capacity over previous year	
		kW	kW	kW	kW	%
1927–1928	490	5 258 257	—	—	—	—
1933–1934	437	7 837 154	—	—	—	—
1934–1935	421	7 785 206	24 822	76 770	−51 948	−0·66
1935–1936	398	8 099 870	448 950	134 286	314 664	4·04
1936–1937	395	8 398 241	404 065	105 694	298 371	3·68
Total net increase over 3 years					561 087	7·16
Total net increase over 10 years					3 139 984	59·71

stations working at high load factors. Table 6 shows various figures for thermal efficiency and coal consumption over the last 3 years and also 10 years.

Compared with a maximum figure of 21 % 10 years ago, the highest thermal efficiency recorded in 1937 shows an improvement of no less than 38 %. As will be seen also from Table 6, similar improvements have been obtained in other major steam generating stations, the mean thermal efficiency of the first 20 and the first 50 stations showing an improvement of 36–32 % over the 10-year period.

The average total coal consumption per unit generated has decreased by no less than 34 % over the 10-year period, a rate of improvement which is substantially greater than that obtained in the United States, in which, over the corresponding period, the figure has been of the order of 20 %.

Generally speaking, it may be said that the efficiency of generation in this country compares favourably with that of any other country.

(2) STEAM CONDITIONS

In the universal desire to improve thermal efficiencies, operating steam pressures and steam temperatures continue to rise. It has usually appeared in the past that these increases tend to take place in more or less definite steps, each of which becomes stabilized for a time.

In an attempt to trace these steps it may be recalled that some 20 to 25 years ago the usual steam conditions were about 200–250 lb./sq. in. at 600–650° F., and the first general radical departure from these was the adoption, some 15 to 20 years ago, of pressures of 350–400 lb./sq. in. at 700–750° F.

During more recent years a large number of power stations have adopted steam conditions of 600–650 lb./sq. in. at 800–850° F.

The latest phase which, it appears, will mark the next main step is the adoption of steam conditions at about 1 300–1 400 lb./sq. in. at 950–970° F.

There has never been any great difficulty in designing turbine plants for higher operating pressures as such, the limiting factor being the troubles associated with the formation of moisture in the turbine exhaust, which gives rise to erosion and possibly ultimate failure of the blades. Initial steam pressures can only be increased provided that steam temperatures are also increased if this moisture is to be kept within safe limits.

The practicability of using higher steam temperatures is a matter which concerns the metallurgists, and in recent years very valuable research work has been carried out in regard to alloys giving satisfactory physical characteristics at higher temperatures, thus enabling high-pressure designs to be evolved. The production of such materials (concerning which further mention is made later), suitable for higher temperatures, has enabled higher pressures to be adopted without increasing the moisture content at the turbine exhaust, and this is the underlying reason of the adoption recently of 1 200–1 400 lb./sq. in. and 950–970° F. already mentioned.

In this country and on the Continent the practice has been to stress the adoption of high steam temperatures.

Table 5

INCREASES IN INSTALLED PLANT CAPACITY IN SELECTED GENERATING STATIONS

(From *Central Electricity Board Annual Reports*)

Year ending 31st December	Number of stations	Total installed capacity	Increase over previous year	
		kW	kW	%
1934	129	6 533 221	—	—
1935	132	6 749 230	216 009	3·32
1936	137	7 206 045	456 815	6·77
1937	137	7 653 570	447 525	6·21
Total net increase over 3 years ..			1 120 349	17·15

In the United States the tendency until fairly recently has favoured the adoption of 750° F. steam temperature, and in order to operate at the higher pressures of about 1 200 lb./sq. in. (for improved efficiency), whilst still keeping to this lower temperature, the reheat cycle has frequently been used.

Due to its complications this cycle has not gained very great acceptance in this country, although there are certain notable and successful examples, such as the Dunston " B " station of the North-Eastern Electric Supply Co., in which the initial conditions are 600 lb./sq. in. at 800° F., with reheating to 800° F. at an intermediate pressure of about 100 lb./sq. in.

Table 6

THERMAL EFFICIENCY AND COAL CONSUMPTION OF STEAM STATIONS IN GREAT BRITAIN

Year ended	31st March, 1928	31st December, 1935	31st December, 1936	31st December, 1937
Number of stations..	344	266	258	242
Total units generated	9 500 598 847	18 106 107 488	20 670 000 000	23 250 000 000
Average coal consumption per unit generated ..	2·16 lb.	1·54 lb.	1·49 lb.	1·43 lb.
Station with highest thermal efficiency—				
Units generated	325 427 230	797 749 600	1 050 147 270	1 206 604 200
Percentage of total units generated	3·43	4·41	5·82	5·19
Thermal efficiency on units generated.. ..	21·07 %	28·59 %	29·14 %	29·05 %
First 20 stations in order of highest thermal efficiency—				
Units generated	2 659 072 395	8 121 579 010	8 954 581 317	10 265 562 810
Percentage of total units generated	27·98	44·85	43·37	44·15
Mean thermal efficiency on units generated ..	18·76 %	24·40 %	25·03 %	25·66 %
First 50 stations in order of highest thermal efficiency—				
Units generated	4 624 857 414	12 560 030 151	14 794 299 518	17 411 851 854
Percentage of total units generated	48·70	69·40	71·60	74·90
Mean thermal efficiency on units generated ..	17·93 %	22·87 %	23·18 %	23·62 %

One of the most outstanding examples of the adoption of the reheat cycle is the Port Washington station of the Milwaukee Electric Railway and Light Co. in the United States, in which the initial conditions are 1 230 lb./sq. in. at 825° F., with reheating at an intermediate pressure of about 400 lb./sq. in. to 825° F., and this station returns the highest recorded thermal efficiency of any steam station in the world.

The latest tendency in the United States appears generally to indicate a swing away from reheating and the adoption instead of the straight regenerative cycle, using steam at 1 200–1 400 lb./sq. in. at 900–925° F.—although there are some exceptions to this practice.

The moisture content in the turbine exhaust can thus be kept down to a satisfactory figure in two ways—first by the use of higher steam temperatures with the straight regenerative cycle, and second by the adoption of lower steam temperatures with the reheat cycle. The latter has the added advantage that it gives a thermal efficiency 4–5 % greater than the straight regenerative cycle for the same initial steam pressure and temperature, but it has the disadvantage that it increases the capital cost and complication of the plant and involves certain difficulties in the matter of operation and flexibility of the plant. It is generally agreed that the reheat cycle is only suitable for base-load stations.

As to other operating conditions, the Loeffler plants, concerning which some comments are given later, adopt steam conditions of 1 900–2 000 lb./sq. in. at 932° F. (with reheating), but in this particular system a high pressure is necessary owing to the excessive pumping power that would be absorbed in the process if lower pressures were adopted.

The highest steam conditions so far adopted are for the new plant which is to be put into service in 1940 at the Twin Branch station of the American Gas and Electric Co., in which the steam will be at a pressure of 2 500 lb./sq. in. and 940° F. With this high pressure a steam temperature considerably in excess of 940° F. would be required on the straight regenerative cycle if the moisture content of the steam at the turbine exhaust were to be kept down to a safe figure, and for this reason it has been necessary to adopt reheating at an intermediate pressure of about 450 lb./sq. in. for this plant.

A principle of operation which has received considerable prominence in the United States during the last few years is that of superimposition, or " topping," which consists of installing new high-pressure boilers and back-pressure turbines, the exhaust from which

Table 7

BRITISH GENERATING STATIONS WITH PLANT INSTALLED OR ON ORDER, OPERATING AT A PRESSURE OF 600 LB./SQ. IN. AND OVER

Station	Operating company	Steam conditions		Number and size of boilers	Number and size of turbines	Date
		lb./sq. in.	° F.	lb./hour	kW	
Brimsdown " A "	North Metropolitan E.P. Co.	1 900–2 000	932–940	2×210 000	1× 52 607	1936
Brimsdown " B "	North Metropolitan E.P. Co.	1 900–2 000	932–940	2×250 000	1× 52 780	1938
Bargoed Colliery	Powell Duffryn Assd. Colls.	1 565	700	2×130 000	2× 6 500	
Battersea " B "	London Power Company, Ltd.	1 420	965	1×550 000	1×100 000	1937
Warrington	Thames Board Mills, Ltd.	1 400	800	2× 81 250		
Dagenham	Ford Motor Company	1 250	750	3×205 000	2× 30 000	1929
Valley Road	Bradford Corporation	1 100	800	1× 86 000		1926
Works	G. & J. Weir, Ltd.	1 000	850	1× 50 000	1× 700†	
Winnington	I.C.I., Ltd.	915	826	4× 96 500		1937
Billingham	I.C.I., Ltd.	815	850	8×270 000	3× 12 500	
Wallerscote	I.C.I., Ltd.	800	797	1× 75 000		1933
Little Barford	Bedfordshire, Cambridgeshire & Huntingdonshire Elect. Co.	675	910	3×300 000		1938
Thorpe	Norwich Corporation	675	875	4×120 000	1× 30 000	1936
Southwick	Brighton Corporation	675	875	4×180 000		1932–34
Southwick	Brighton Corporation	675	875	2×215 000		1935
Hams Hall " B "	Birmingham Corporation	670	845	3×350 000	2× 53 000	1938
Valley Road	Bradford Corporation	650*	850	2×200 000		1937
Stourport	Shropshire, Worcestershire & Staffordshire E.P. Co.	650	850	3×182 000	2× 30 000	1936
Upper Boat	South Wales Power Co.	650*	850	2×182 000	1× 30 000	1937
Clarence Dock	Liverpool Corporation	630	825	6×250 000	2× 51 250	1936–37
Barking	County of London E.S. Co.	625	825	12×256 000	4× 75 000	1931–36–37
Littlebrook	Kent Electric Power Co.	625	825	6×256 000	1× 60 000 2× 30 000	1937
Dalmarnock	Glasgow Corporation	625	850	6×200 000	2× 50 000	1935
Dunston " B "	North-Eastern E.S. Co.	625	800*	6×180 000	4× 50 000	1931
Dunston " B "	North-Eastern E.S. Co.	625	800*	6×156 000		
Fulham	Fulham Borough Council	625	850	8×260 000	3× 60 000	1935
Gunwharf Road	Portsmouth Corporation	625	850	2×150 000	1× 30 000	
Kearsley	Lancashire Electric Power Co.	625	850	8×172 000	2× 51 600	1935–36
Hartshead	Stalybridge, Hyde, Mossley, & Dukinfield Tramways & E.B.	625	850	3×180 000	1× 30 000	1936
Neepsend	Sheffield Corporation	625	850	5×187 500	1× 30 000	1934–36
North Wilford	Nottingham Corporation	625	850	4×254 000	1× 30 000	1934
Prince of Wales	Rotherham Corporation	625	850*	2×200 000	1× 25 000	1936
Tir John	Swansea Corporation	625	850	4×240 000	2× 30 000	1932
Battersea " A "	London Power Company, Ltd.	615	850	3×375 000	1×105 000	1935
Battersea " A "	London Power Company, Ltd.	615	850	6×312 000	2× 69 000	1928
Blackburn Meadows	Sheffield Corporation	600	825	3×156 000	2× 30 000	1929
Blackburn Meadows	Sheffield Corporation	600	825	3×187 500	1× 50 000	1934
Ferrybridge	Yorkshire Electric Power Co.	600*	825	8×135 000	2× 45 000	
Newport	Newport Corporation	600*	800	2×150 000	1× 30 000	1938
Runcorn	Imperial Chemical Industries	600*	800	2×150 000		1934–35

* Pressure or temperature at turbine stop-valve.

† Topping unit.

Table 8

PERCENTAGES OF TOTAL BOILER PLANT INSTALLED IN GREAT BRITAIN, WORKING AT VARIOUS STEAM PRESSURES

Year	1927–28	1933–34	1934–35	1935–36	1936–37
	%	%	%	%	%
Working Pressures—					
Below 200 lb./sq. in.	25·6	13·0	12·0	9·9	8·5
Above 200 lb./sq. in.	74·4	87·0	88·0	90·1	91·5
Above 300 lb./sq. in.	13·6	35·5	36·7	41·3	47·1
Above 400 lb./sq. in.	*	*	*	15·8	21·3
Above 500 lb./sq. in.	*	*	*	*	13·3

* Figures not available.

is taken into the existing low-pressure mains in the station.

The high-pressure turbine or " primary " unit is comparatively small in size, being arranged to run at a high speed of 3 000–3 600 r.p.m., and it has no condensing plant or ancillary equipment, with the result that it can usually be accommodated in the existing turbine room. With this system the thermal efficiency of the existing stations may be increased within the limits of 15–35 %, depending upon the low-pressure conditions, at minimum capital outlay. The present tendency is to use steam conditions of about 1 200–1 400 lb./sq. in. and 900–925° F. for the high-pressure boilers and primary unit.

There is no indication at present of any development of the binary-fluid cycles. Several years ago, when these were first introduced, the efficiencies which they gave marked a very substantial increase on the efficiencies of the then-existing straight steam plants, but improvements to the latter in recent years and the adoption of higher steam pressures and temperatures have done much to reduce this apparent difference, and this, added to the fact that the binary-fluid plants have been by no means free from trouble, has tended virtually to bring their adoption to a standstill for the present.

Table 7 gives a list of steam conditions for plants installed or on order in this country, and the large number falling within the 600–650 lb./sq. in. range will be noted. The general tendency in this country towards the adoption of higher steam pressure is also illustrated in Table 8, which shows approximately the percentage of total boiler plant installed at various ranges of operating pressures.

Table 9 shows the terminal conditions for the steam stations which have given the highest thermal efficiency of any steam station in this country over the last 12 years.

(3) TURBINE PLANTS AND AUXILIARIES

(a) Size of Units

The size of unit for a particular station is determined from considerations of the nature of the load curve, but the interconnection of stations by the grid has enabled larger and more efficient units to be adopted than would otherwise have been the case.

There has been no suggestion in recent years to build units of an output equivalent to the 208 000-kW set which was installed some 8 or 9 years ago at the Illinois State Line station.

Whilst several 150 000-kW units have been built for

Table 9

TERMINAL CONDITIONS FOR STEAM STATIONS GIVING THE HIGHEST THERMAL EFFICIENCY FOR THE PERIOD 1926–1937

Year ending	Station	Company	Thermal efficiency on units generated	Total units generated	Steam pressure	Steam temp.	Abs. press. at turbine exhaust	Feed temp.
					At turbine			
			%		lb./sq. in.	° F.	lb./sq. in.	° F.
31st March, 1926	Barton ..	Manchester Corpn.	21·51	269 036 130	352	655	0·48	200
31st March, 1927	Barton ..	Manchester Corpn.	21·83	300 771 400	354	662	0·49	202
31st March, 1928	Barton ..	Manchester Corpn.	21·07	325 427 230	358	684	0·49	201
31st March, 1929	Padiham ..	Lancashire E.P. Co.	21·35	67 043 877	245	597	0·313	123·5
31st Dec., 1930	Kearsley ..	Lancashire E.P. Co.	23·84	129 624 646	306	687	0·422	195
31st Dec., 1931	Deptford West	London Power Co.	24·02	314 933 020	369	756	0·428	239
31st Dec., 1932	Clarence Dock	Liverpool Corpn...	24·72	204 866 910	440	705	0·43	268
31st Dec., 1933	Clarence Dock	Liverpool Corpn...	26·06	275 891 530	438	709	0·475	276
31st Dec., 1934	Barking " B "	County of London	27·95	580 180 000	610	812	0·443	305
31st Dec., 1935	Battersea ..	London Power Co.	28·59	797 749 600	600	824	0·438	323
31st Dec., 1936	Battersea ..	London Power Co.	29·14	1 050 147 270	592	826	0·438	327
31st Dec., 1937	Battersea ..	London Power Co.	29·09	1 206 604 200	593	829	0·457	330

base-load stations in the United States, in this country sizes ranging from 50 000 to 100 000 kW appear to be favoured for the larger stations, and nearly 50 units having a capacity of 50 000 kW or over have been installed or are on order. For the smaller stations 30 000 kW has become largely standardized.

Table 10 shows a list of turbine units having a capacity of 50 000 kW or above, which are installed or on order in this country.

(b) Speeds

It has not been the practice so far in stations in this country to adopt speeds in excess of 1 500 r.p.m. for units of 50 000 kW or above, although British manufacturers have built several sets for use abroad. Speeds of 3 000 r.p.m., however, are becoming very usual with units having a rating of about 30 000 to 40 000 kW in this country.

Table 11 gives a list of a number of units installed or on order in this country, running at 3 000 r.p.m. and having a capacity of 25 000 kW or above.

The higher speeds have an advantage, more particularly in high-pressure work, in that they enable size and capital cost to be reduced whilst increasing the efficiency.

(c) Type

The most usual form of unit at present being installed is the single-shaft tandem compound with two cylinders, except in the case of the largest sizes where three cylinders are used. For highest efficiencies the low-pressure cylinders are arranged with double-flow exhausts. An exception to the single-shaft machine will be the new plant which is being installed at Battersea " B," which comprises a 16 000-kW, high-pressure single-cylinder primary back-pressure set running at 3 000 r.p.m., and an independent 84 000-kW, 2-cylinder secondary condensing set running at 1 500 r.p.m.

(d) Blading

Mention has already been made of the question of blade erosion resulting from the formation of moisture in the turbine exhaust, and it was pointed out that so far as possible these conditions are selected in order that excessive moisture should not occur. It is usual to keep within the limit of about 12 %, but with the latest designs of blades, having erosion strips combined with special arrangements of inter-stage drainage, figures up to 14 % are permissible. The blade protection takes the form of welding some specially hard material on to the leading edge of the blades in the last rows.

Inter-stage drainage has received considerable attention in recent years and will continue to do so, for by this means it is possible to reduce the cumulative effect of moisture formed in the last rows of blades, so that the wetness content of the steam passing through the final stages is less than that which would correspond to the normal expansion curve if no such means were adopted.

Experiments have also been carried out with the installation of separators in the interconnecting pipes between the intermediate-pressure and low-pressure cylinders of 3-cylinder machines.

(e) Condensers

Condenser design has not undergone any very radical alteration in recent years. The necessity for reducing the oxygen contents of the condensate to the lowest possible figure becomes of increasing importance as operating steam pressures and temperatures are increased. With this end in view it is essential that ample steam paths should be provided through or round the tube nest, and that the air offtake should be removed as far as possible from the condensate outlet.

Amongst the largest single-shell condensers in this country will be the 70 000-sq. ft. unit for the 100 000-kW set for Battersea " B."

(f) Feed-Water Heaters

The present practice is to provide one feed-water heater for approximately each 50 deg. F. of temperature rise of the condensate, and to use final feed-water temperatures of about 350° F. for the larger units operating at the higher pressures and temperatures, as may be seen from Table 10.

This involves the use of a number of high-pressure heaters, and the hairpin-bend or loop-type heaters expanded at each end into forged-steel tube plates or headers are usually adopted. The most usual material employed for the tubes is copper or cupro-nickel.

For extra-high-pressure heaters the general tendency is to adopt solid forged headers with internal manhole doors.

One of the latest developments is to incorporate the flash chambers in the extended lower portion of the heater casing instead of using separate external flash boxes.

(g) Auxiliaries

The increase in size of turbine units has necessitated the incorporation of certain additional auxiliaries, such as motor-driven barring gear to keep the machine continuously in rotation when warming through, and also when taking off load, the object being to obtain even heating and cooling throughout. Also, jacking pumps are provided which supply high-pressure oil to the underside of the shaft in the bearings, to overcome frictional resistance on starting up.

Boiler feed-pumps are usually of the centrifugal type. Reciprocating pumps give higher efficiency, but their capital cost and the space they occupy tend to outweigh this advantage and, furthermore, smoother delivery pressures are obtained with the centrifugal type. It is usual to arrange the boiler feed-pumps on the inlet side of the high-pressure heaters so that they handle water at lower temperatures, a procedure which simplifies the gland-sealing and cooling arrangements.

(4) BOILER PLANTS

(a) Size of Units

In recent years there has been a movement towards increasing the evaporative capacity of boiler units, and there are now installed or on order in this country about 100 plants having a maximum continuous rating of 200 000 lb./hour and over, as shown in Table 12.

The most popular size appears to be about 200 000–250 000 lb./hour, although capacities of 300 000–350 000 lb./hour are now being adopted for the larger base-load stations. The largest unit on order in this country is the 550 000-lb./hour e.h.p. boiler for the Battersea " B " station. In the United States, whilst a few boilers of 600 000, 700 000, 900 000, and even 1 000 000 lb./hour have been built, the general practice appears to be to standardize units of about 500 000 lb./hour.

(b) Rating

In the matter of rating, the general inclination is to fix the " maximum continuous rating," the limiting considerations of which are the capacities of the fans, the maximum permissible gas and air temperatures, and the maximum capacity of the coal-burning equipment. In addition, it is usual to fix a " normal economic rating " at about 80 % of the maximum continuous rating, at which capacity the plant components operate most efficiently and the chimney losses are reduced to as low a value as possible.

Table 10

British Power Stations with Turbo-Alternators Installed or on Order having an Output of 50 000 kW or over

Station	Operating company	Number off	Capacity	Steam conditions		Vacuum	Final feed temp.	Date
				Pressure	Temp.			
			kW	lb./sq. in.	° F.	in. Hg	° F.	
Battersea " A " ..	London Power Company, Ltd.	1	105 000	600	850	29·1	355	1933
Battersea " B " ..	London Power Company, Ltd.	1	100 000	1 350	950	29·1	400	1937
Barking " B " ..	County of London E.S. Co.	4	75 000	600	800	29·0	340	1930–35–37
Battersea " A " ..	London Power Company, Ltd.	2	69 000	600	850	29·1	340	1928
Fulham	Fulham Borough Council ..	3	60 000	600	800	29·0	358	1932–36
Littlebrook ..	Kent Electric Power Co. ..	1	60 000	600	800	29·0	340	1936
Hams Hall " B " ..	Birmingham Corporation ..	2	53 500	650	825	28·5	340	1938
Brimsdown " B " ..	North Metropolitan E.P. Co.	1	52 780	1 900	930	28·5	361	1938
Brimsdown " A " ..	North Metropolitan E.P. Co.	1	52 607	1 900	930	28·5	361	1935
Kearsley	Lancashire Electric Power..	2	51 600	600	800	28·75	280	1935–36
Clarence Dock No. 2	Liverpool Corporation ..	2	51 500	600	800	29·0	342	1936
Barton	Manchester Corporation ..	1	51 500	350	825	28·8	310	1935
Hams Hall " A " ..	Birmingham Corporation ..	3	51 500	350	730	28·0	306	1934–36
Clarence Dock No. 1	Liverpool Corporation ..	2	51 500	400	725	29·0	300	1929–30
Portishead	Bristol Corporation ..	2	51 250	300	800	29·0	307	1928–36
Ironbridge	West Midlands J.E.A. ..	4	50 000	375	750	28·9	315	1929–34–36–37
Dunston " B " ..	North Eastern E.S. Co. ..	4	50 000	600	800	29·0		1930–37
Deptford West ..	London Power Company ..	1	50 000	350	750	29·1	250	1936
Blackburn Meadows	Sheffield Corporation ..	2	50 000	570	825	28·0	265	1936–38
Dalmarnock ..	Glasgow Corporation ..	2	50 000	600	825	29·0	320	1935

The maximum continuous rating is important in that it determines the maximum output that can be obtained at times of peak load or emergency, and normal economic rating is equally important, in that it determines the general efficiency of the plant, since it will operate for the major portion of its life at about this rating.

(c) Relationship between Boiler and Turbine Plant Capacity

The ratings of boiler units must necessarily be fixed in relation to the turbine plant which they serve, and there appear at present to be two extremes in this connection. The first, which has been developed in the United States, is to provide one boiler unit per turbine, and much has been written on this subject.

This scheme is obviously the cheapest, since the capital cost per unit of output decreases as the capacity increases. However, it demands an availability on the boiler plant comparable with that on the turbine plant, and whilst the present bias in boiler design is towards improving the availability factor, yet it is doubtful if it can be said in the present state of the art that this has yet attained the values which can be obtained with turbine plant.

The second method is to provide 3 boiler units for each turbine unit, arranging these with a capacity such that any 2 units can steam the turbine up to its maximum continuous rating. This gives great flexibility of operation and ensures continuity of supply, even when trouble is experienced on one of the boiler plants, but the capital cost is high.

The scheme which appears to form the best compromise between these extremes is to provide 2 boiler units for each turbine unit, fixing the capacities so that with both boiler units in service they can steam the turbine up to its maximum continuous rating whilst themselves operating at their normal economic rating, and further fixing the maximum continuous rating of each boiler so that one can steam the turbine up to about 70 % of its maximum continuous rating.

The advantage of this scheme is that the boilers are normally both steamed together at an easy rating, which considerably improves their availability, and at the same time a substantial output can still be obtained from the turbine in the event of trouble being experienced with either of the boiler units.

Table 11

TURBINE UNITS INSTALLED OR ON ORDER IN GREAT BRITAIN WITH AN OUTPUT OF 25 000 kW AND OVER, AND OPERATING AT 3 000 R.P.M.

Station	Operating company	Number off	Turbine output kW
Ferrybridge	Yorkshire Electric Power Co.	2	40 000
Back O' Th' Bank	Bolton Corporation	1	31 250
Hartshead	Stalybridge, Hyde, Mossley, & Dukinfield T. & E. Board	1	31 250
Stuart Street	Manchester Corporation	2	30 750
Freemans Meadow	Leicester Corporation	1	30 000
Hardingstone	Northampton E.L. & P. Co.	2	30 000
Tir John	Swansea Corporation	2	30 000
Millgate	Stockport Corporation	1	30 000
Spondon	Derbyshire and Nottinghamshire E.P. Co.	2	30 000
Longford	Coventry Corporation	3	30 000
Upper Boat	South Wales Power Company	2	30 000
Kilmarnock	Ayrshire Electricity Board	1	30 000
Limehouse	Stepney Electric Supply	1	30 000
Sculcoates	Hull Corporation	1	30 000
Woolwich	Woolwich Corporation	1	30 000
Clyde Mill	Clyde Valley E.P. Co.	1	30 000
Neepsend	Sheffield Corporation	2	30 000
Croydon	Croydon Corporation	1	30 000
Gunwharf Road	Portsmouth Corporation	1	30 000
Kirkstall	Leeds Corporation	2	30 000
Littlebrook	Kent Electric Power Co.	2	30 000
New Harbour	Belfast Corporation	2	30 000
Yoker	Clyde Valley E.P. Co.	2	30 000
North Wilford	Nottingham Corporation	1	30 000
Thorpe	Norwich Corporation	1	30 000
Stourport	Shropshire, Worcestershire, and Staffordshire E.P. Co.	3	30 000
Carolina Port	Dundee Corporation	1	30 000
Thornhill	Yorkshire Electric Power Co.	1	30 000
West Ham	West Ham Corporation	1	30 000
Millfield	Borough of Hackney	2	30 000
Blackburn Meadows	Sheffield Corporation	2	30 000
Portobello	Edinburgh Corporation	1	30 000
Derby	Derby Corporation	1	30 000
Southampton	Southampton Corporation	2	25 000
Brimsdown	North Metropolitan E.P. Co.	2	25 000
Prince of Wales	Rotherham Corporation	1	25 000
Croydon	Croydon Corporation	1	25 000
Blackburn Meadows	Sheffield Corporation	1	25 000
North Tees	North-Eastern E.S. Co.	1	25 000

(d) Water Walls and Boiler Heating Surface

One of the most marked tendencies in modern boiler design is to reduce substantially the amount of convection boiler-heating surface provided, and to increase considerably the amount of radiant water-wall surface, and this practice may be attributed to two main causes.

First, the heat transfer on water walls is substantially greater than that in ordinary boiler convection surface, with the result that for a given duty very much less surface is required, resulting in a saving in weight and cost of the pressure heating surface.

The other main cause is the prevalence of using much higher operating steam pressures and temperatures, which increases considerably the ratio of the heat absorbed in superheating the steam to the heat absorbed in converting the steam from water to saturated steam.

In the result the surface of the superheater is considerably increased, and in order to achieve the higher steam temperatures this surface has to be in a zone of much higher gas temperature, and hence has to be nearer to the furnace than is the case with lower steam temperatures. The net result of this has been a considerable reduction in the convection boiler-heating surface as such —and in fact, in some of the latest high-pressure, high-temperature designs, it merely constitutes a widely-spaced tube screen between the boiler outlet and the superheater inlet.

It is not possible in a review of this kind to go into details of boiler-plant design, and in any case it is not a subject upon which it is easy to generalize, since the design and disposition of the various heating surfaces are matters which must be considered individually for each plant, depending as they do upon the terminal conditions, type of fuel to be burnt, fusion temperature of the ash, and so on.

In the matter of types of water walls, it appears that the common procedure at present is to provide all-metal faces to these walls, either by attaching cast-iron-faced blocks to the tubes or arranging the pitching of the bare tubes so that they present a continuous metal surface.

The question of circulation in water walls is a matter of considerable importance, and it is a first essential that the downcomer pipes should be arranged in a cool zone.

The question of providing re-circulating pipes between inlet and outlet water-wall headers is a matter concerning which there is no general agreement at present, and water walls are in service and operating satisfactorily both with and without these re-circulators.

Present tendencies appear to indicate a preference for the bent-tube type of boiler, particularly in the case of higher-pressure boilers, owing to the absence of multitudinous hand-hole caps necessary with the header type.

With increased operating pressures the scantlings and weights of the drums increase rapidly, and the present trend is towards reducing the number and size of these drums, and, in fact, only two drums are provided in some of the latest designs of bent-tube boilers having a small actual convection heating surface.

In view of the growing importance of preventing carry-over into the superheaters and turbines, it is usually considered advisable to provide a dry drum between the saturated-steam drum and the superheater inlet, in which the final separation of entrained water or solids can be achieved.

Table 12

British Power Stations with Boilers Installed or on Order having a Capacity of 200 000 lb./hr. or over

Station	Operating company	No. off	Capacity	Steam pressure	Steam temp.	Feed temp.	Air temp.	Type of firing
			lb./hour	lb./sq. in.	° F.	° F.	° F.	
Battersea " B " ..	London Power Company, Ltd.	1	550 000	1 420	965	400	90	R.S.
Battersea " A " ..	London Power Company, Ltd.	3	375 000	615	850	355	90	R.S.
Deptford West ..	London Power Company, Ltd.	1	350 000	375	780	240	100	R.S.
Hams Hall " B "	Birmingham Corporation ..	3	350 000	670	845	340		P.F.
Battersea " A " ..	London Power Company, Ltd.	6	312 000	615	850	355	90	R.S.
Little Barford ..	Bedfordshire, Cambridgeshire & Huntingdonshire Elec. Co.	3	300 000	675	910			P.F.
Deptford West ..	London Power Company, Ltd.	2	300 000	375	780	240	100	R.S.
Hams Hall " A "	Birmingham Corporation ..	6	300 000	375	730			C.G.S.
Hams Hall " A "	Birmingham Corporation ..	3	300 000	375	730			P.F.
Ironbridge ..	West Midlands J.E.A. ..	10	270 000	400	800	315	100	C.G.S.
Fulham	Fulham Borough Council ..	8	260 000	625	850	350		R.S.
Littlebrook ..	Kent Electric Power Co. ..	6	256 000	625	825	340		3-C.G.S.; 3-P.F.
Barking	County of London E.S. Co. ..	12	256 000	625	825	340		C.G.S.
North Wilford ..	Nottingham Corporation ..	4	254 000	625	850			P.F.
Clarence Dock ..	Liverpool Corporation ..	6	250 000	630	825	342		C.G.S.
Brimsdown " B "	North Metropolitan E.P. Co.	2	250 000	1 900–2 000	932–940	355–360		C.G.S.
Brimsdown " A "	North Metropolitan E.P. Co.	2	210 000					C.G.S.
Tir John ..	Swansea Corporation ..	4	240 000	625	850	350		P.F.
Hams Hall " A "	Birmingham Corporation ..	5	228 000	375	730			P.F.
Southwick ..	Brighton Corporation ..	2	215 000	675	875			
Kirkstall ..	Leeds Corporation	3	200 000	490	750	300	70	P.F.
Clarence Dock ..	Liverpool Corporation ..	4	200 000	450	775			
Southampton ..	Southampton Corporation ..	3	200 000	425				
Prince of Wales ..	Rotherham Corporation ..	2	200 000	625	850			C.G.S.
Valley Road ..	Bradford Corporation ..	2	200 000	650	850	350		R.S.
Freemans Meadow	Leicester Corporation ..	2	200 000	360	800			P.F.
Barton	Manchester Corporation ..	2	200 000	375	855	310		C.G.S.
Deptford West ..	London Power Company, Ltd.	4	200 000	375	780	240	100	R.S.
Dalmarnock ..	Glasgow Corporation ..	6	200 000	625	850	320		C.G.S.

(e) Combustion Chambers

A noticeable feature of recent boiler designs is the provision of very large combustion chambers, this resulting from the desire to do as much work as possible on the radiant-heat water-wall surfaces of the combustion chamber and to reduce the energy release rate in the furnace with the object of increasing the availability factor.

There has been a movement in some of the latest designs of boilers in the United States to provide double combustion chambers, but it is too early yet to state what measure of success has attended this design.

(f) Firing

In this country stoker firing of large boilers predominates, whereas in the United States pulverized fuel tends to become almost universally adopted. This is a matter which always gives rise to lively discussion between the protagonists of the two systems, and apart from special considerations concerning the nature of the fuel to be burnt it is probably determined principally by the common usage and experience of the engineers concerned. Some years ago it was contended that pulverized-fuel firing had the advantage that it enabled boiler units of larger capacity to be constructed, but this suggested limitation in stoker capacity has now been overcome and it is easily possible to construct a stoker-fired unit having a capacity of 500 000 lb./hour and even higher.

In the matter of efficiency, there is probably very little to choose between the two forms of firing.

(5) SPECIAL DESIGNS OF BOILERS

One of the interesting features of recent years has been the development of special designs of boilers operating on the forced-circulation principle, this tendency being more marked on the Continent than in this country or America.

The adoption of higher steam pressures has probably been largely responsible for this, since the resulting increase in density of steam has made the problem of natural circulation more difficult.

There are many claims made for these types of boilers, such as the ability to use smaller-diameter tubes, and hence reduced metal thicknesses and weights, this being possible since with forced circulation there is no need to keep down the frictional resistance of the tube system by providing large flow areas such as are necessary with natural circulation.

Also, it is claimed that the various heating surfaces can be much better disposed to give maximum efficiency of heat absorption, since much more licence can be taken in the layout.

It is again claimed that the positive flow in the tubes obtained with forced circulation eliminates any stagnant areas which may occur with natural circulation, in which solids can settle out on the walls, giving rise to the accumulation of scale which might result in eventual overheating of the metal. From this it would follow that purity of feed water is not of such great importance with forced-flow boilers, but further experience is necessary to demonstrate whether this claim is well founded or not.

It is probably true that a unit of greater output can be installed in a given space with the forced-circulation system than with a natural-circulation boiler.

The boilers can be classified generally into three types, which may be briefly described as follows:—

(a) Once-Through Boilers, such as the Benson, Sulzer, and Ramsin

In this type the feed water is delivered by the boiler feed-pump into one end of the tube system of the unit, which comprises an economizer, boiler, and superheater, arranged in series, superheated steam issuing finally at the other end of the tube system, exactly as much water being forced through the heating surface as is converted into steam.

As the name signifies, the water passes through the system once only, and the distinguishing feature is the absence of any drum for the separation of the saturated steam from the water. This separation takes place actually in the tubes themselves at a point towards the end of the " boiler " section, and it follows that accurate automatic controls and thermostatic devices are necessary to regulate the water and fuel supply strictly in accordance with the steam demand, in order to maintain the production of superheated steam at a constant temperature.

(b) Forced-Water-Circulation Boilers, such as the La Mont and Velox

In this type the tubular system of the boiler (and water walls) proper comprises a closed circuit with a water-circulating pump in the system which continually draws water at a constant rate from the drum and discharges it through the complete tube system back to the drum as a steam-and-water mixture. The economizer and superheater are of conventional type and are not subject to forced flow.

It is the least radical departure from the normal natural-circulation boiler, and is equivalent to inserting a pump in the water circulatory system, this operating on a comparatively low pressure-differential of about 30–40 lb./sq. in. and circulating continuously a constant quantity of water irrespective of the boiler output, the amount being equivalent to about 6 to 8 times the maximum output of the boiler.

The main features of design depend upon the arrangement of the large number of individual water circuits in parallel, so that an equal amount of water passes through each. Also, protective devices are necessary to take care of the possibility of temporary failure of the pump, these having as their function to switch in a standby pump in this event, and/or to shut down the boiler in the case of complete failure of the forced-circulation system.

The Velox boiler embodies many other special features in addition to the forced-circulation principle, such as the provision of a gas turbine driven by the exhaust gases from the boiler, this turbine driving an air compressor which supplies the combustion air at about 30–40 lb. sq. in., thus enabling extremely high heat-release values to be obtained in the combustion chamber, and so reducing very materially the space occupied by the plant for a given output.

(c) Forced-Steam-Circulation Boilers, such as the Loeffler

In this type, steam is withdrawn from the drum by a pump and is forced through the superheaters, the quantity being regulated according to the output of the boiler and always being in excess thereof. The surplus superheated steam is discharged back to the steam drum, and the heat is utilized in converting into saturated steam some of the water in the drum.

The drum is located in a position external to the boiler setting. The tubular heating surface of the boiler contains steam only, there being no water circulation. This type of boiler is only suitable for pressures above 1 100 lb./sq. in., because of the great power required to circulate steam at lower pressures.

Examples in this Country

Whilst the development of these special types of boiler has been carried out principally on the Continent, there are examples of most types in this country, as may be seen from Table 13, which shows a list of these special boilers installed or on order.

(6) MATERIALS AND CONSTRUCTION

(a) Materials

The adoption of higher operating steam pressures and temperatures had made it necessary to consider very carefully the chemical constituents, physical properties, and heat treatment, of the steel to be used for the boiler, superheater, the steam piping, and the high-pressure end of the turbine.

When steel is exposed to high temperatures for long periods under stress it is subject to continued permanent deformation or creep, which is a measure of the total strain that results in a given time from the application of a given stress.

It is usually permissible to take a life of 100 000 hours (continuous), and to allow a strain of 0·001 in. per inch during this period for most portions of the plant, although a strain of 0·003 in. per inch can be used for tubes and pipes. If the creep stress which will produce this strain rate for a given material is plotted against temperature, it will be found that there is a very rapid fall as the temperature is carried above 800° F.

For example, with ordinary carbon steel the stress which will produce a strain of 0·001 in. per inch in 100 000 hours at 800° F. is about 4–6 tons per sq. in., depending upon the conditions and heat treatment. The corresponding stress at 850° F. is about 2½–3½ tons per sq. in., at 900° F. about 1½ tons per sq. in., and at 950° F. it falls to about 1 ton per sq. in. only.

It is the rapid diminution in creep stress with temperature which has brought this factor into such prominence recently with the adoption of higher operating steam temperatures.

The mere increase of sectional area of plant components for higher temperatures to keep down the working stress to such reduced figures as are required for permissible creep is not in itself a solution to the problem, as this may involve other difficulties, e.g. internal thermal stresses, lack of flexibility, etc. It is for this reason that much has been done in recent years to evolve suitable alloys to give improved creep properties.

It is not possible in a general review of this type to detail the great amount of work which has been done in this connection in recent years by many eminent research workers. However, it is generally accepted that the addition of molybdenum confers improved creep properties to

Table 13

Special Forced-Circulation Type Boilers Installed or on Order in Great Britain, 1938

Name of station	Name of operating company	No. off	Capacity N.E.R.	Capacity M.C.R.	Steam pressure	Steam temp.	Feed temp.	Air temp.	Type of firing	Notes
			lb./hour	lb./hour	lb./sq. in.	° F.	° F.	° F.		
(1) La Mont Boilers										
Deptford West . .	London Power Company	1	280 000	350 000	350	780–850	240	100	Retort stoker	
H.M. Ship . . .	Admiralty . . .	1	110 000	126 000	300	640	211	80	Oil burners	
Wallerscote Works, Northwich . .	Imperial Chemical Industries	1	60 000	75 000	800	777	356	100	Chain-grate stoker	
Works, Glasgow . .	G. & J. Weir, Ltd. . .	1	40 000	50 000	1 000	850	216	60	Chain-grate stoker	
(2) Sulzer Boilers										
Bargoed Colliery . .	Powell Duffryn Associated Collieries, Ltd.	2	110 000	130 000	1 565	770	445		Pulverized fuel	Also re-heating at 366 lb./sq. in. to 770° F.
Warrington . . .	Thames Board Mills, Ltd.	2	65 000	81 250	1 400	800	300		Chain-grate stoker	
(3) Loeffler Boilers										
Brimsdown "A" . .	North Met. Elect. Power Supply Co.	2	175 000	210 000	1 900–2 000	932–940	355–362		Chain-grate stoker	Also re-heating at 200 lb./sq. in. to 810° F.
Brimsdown "B" . .	North Met. Elect. Power Supply Co.	2	200 000	250 000	1 900–2 000	932–940	355–362		Chain-grate stoker	Also re-heating at 315 lb./sq. in. to 840° F.
(4) Velox Boilers										
Haslar Experimental Station	Admiralty . . .	1	—	112 000	300	630	150–250	77	Oil pressure combustion	

ordinary low-carbon steel, and ½% molybdenum steel is now being used extensively in the high-temperature portions of power-station plant, both in this country and abroad.

Recent investigations in this country have also shown that the addition of vanadium to ½% molybdenum low-carbon steel gives still further improved creep properties.

Another factor which is of great importance in higher-temperature working is the question of oxidation of the metal, and in this direction chromium has been found to confer useful properties as an inhibitor. Chromium does not, however, improve the creep properties of the material, and, in fact, as the percentage is increased it tends to reduce the creep strength.

In the United States steel containing ½% molybdenum and 4–6 % chromium has gained considerable popularity, having good creep properties and resistance to oxidation. In this country the tendency is to use steels having ½% molybdenum with only about 1% of chromium.

There are, of course, many other complex alloys which have been produced for heat-resisting steels; these include such metals as silicon, tungsten, titanium, etc., but the decision as to the most suitable alloy has to be considered in each instance in terms of the service which the plant component has to perform.

(b) High-Pressure and High-Temperature Steam Pipework

In addition to the question of the material to be used for steam pipework, a problem which has received very special consideration as a result of the adoption of higher steam pressures and temperatures is the design of the pipework and the joints, etc.

The general tendency appears to be to eliminate flange joints as far as possible, and pipe-to-pipe joints in steam lines are being made with some form of solid butt welds.

In the United States the disposition is to eliminate flanges altogether, even for terminal connections, and at points where valves and fittings are inserted in the line, these connections also being made by solid butt welds similar to the pipe-to-pipe connections.

In this country heavy flange connections are still favoured in these locations, but provision is usually made for weld-sealing these joints.

A special committee appointed by The Institution of Mechanical Engineers is at present doing valuable work in connection with the design of flanged joints for high steam pressures and temperatures.

The extensive use of butt welding has become possible as a result of concentrated investigations into the question of welding and the subsequent heat treatment necessary afterwards for the purpose of stress relieving. Whilst much investigation has been carried out *inter alia* in connection with the form of pipe ends for butt welding and the type of rods to be used, the success of welded joints depends very largely upon the efficiency of the operator, and in recent years much time has been devoted to the training of these operators for this work in order to obtain the highest standard of efficiency.

(7) ELECTRICAL EQUIPMENT

(a) Alternators

One interesting development in recent years has been the winding of alternator stators for 33 kV and upwards in order to eliminate step-up transformers. In Table 14

Table 14

TURBO-ALTERNATORS OF 25 000-kW OUTPUT AND OVER, INSTALLED OR ON ORDER IN THIS COUNTRY WITH HIGH-VOLTAGE WINDINGS OF 20 kV AND UPWARDS

Station	Operating company	Winding voltage	Number and size of sets
		kV	kW
Derby	Derby Corporation	36	1 × 30 000
Freemans Meadow	Leicester Corporation	36	1 × 30 000
Hardingstone	Northampton E.L.P. Co.	36	2 × 30 000
Brimsdown "A"	North Metropolitan E.P. Co.	33	1 × 52 607
Brimsdown "B"	North Metropolitan E.P. Co.	33	1 × 52 780
Kearsley	Lancashire E.P. Co.	33	2 × 51 600
Barton	Manchester Corporation	33	1 × 51 500
Clarence Dock	Liverpool Corporation	33	2 × 51 250
Hams Hall "B"	Birmingham Corporation	33	3 × 50 000
Ironbridge	West Midlands J.E.A.	33	4 × 50 000
Tir John	Swansea Corporation	33	2 × 30 000
Carolina Port	Dundee Corporation	33	1 × 30 000
Longford	Coventry Corporation	33	3 × 30 000
Upper Boat	South Wales Power Co.	33	2 × 30 000
Brimsdown	North Metropolitan E.P. Co.	33	2 × 25 000
Upper Boat	South Wales Power Co.	33	1 × 25 000
Deptford West	London Power Company, Ltd.	22	1 × 50 000
Kilmarnock	Ayrshire Electricity Board	22	1 × 30 000
Sculcoates	Hull Corporation	22	1 × 30 000
Woolwich	Woolwich Corporation	22	1 × 30 000
Dalmarnock	Glasgow Corporation	20	2 × 50 000

is given a list of machines of 25 000 kW and above with high-voltage windings, which are installed or on order in this country.

As will be seen from Table 11, a large number of alternators with ratings of from 25 000 to 40 000 kW, running at a speed of 3 000 r.p.m., have been built.

One of the most interesting developments in connection with alternators during the last few years has been the adoption of hydrogen cooling. Orders have been placed in America during the last 3 years for 33 of such generators with a capacity of nearly 1½ million kW, a list of these plants being given in Table 15.

Table 15

HYDROGEN-COOLED TURBO-GENERATORS INSTALLED OR ON ORDER IN THE UNITED STATES OF AMERICA

Station	Operating company	Number and size of units	Speed
		kW	r.p.m.
State Line	Chicago & District Gas & Elect.	1 × 150 000	1 800
River Rouge	Ford Motor Company	1 × 110 000	1 800
Oswego	Niagara Hudson Company	1 × 80 000	1 800
Cahokia	Union Electric Light & Power	1 × 75 000	1 800
Columbia	Cincinnati Gas & Electric Co.	1 × 65 000	1 800
Windsor	Ohio Power Company	2 × 60 000	3 600
James H. Read	Duquesne Light Company	1 × 60 000	1 800
Waterside	Consolidated Edison Co.	2 × 53 000	3 600
Essex	Public Service Elec. & Gas Co.	1 × 50 000	3 600
Springdale	West Penn Power Co.	1 × 50 000	3 600
Schuylkill	Philadelphia Electric Co.	1 × 50 000	3 600
Logan	Appalachian Electric Power Co.	1 × 40 000	3 600
Manchester Street	Narragansett Electric Co.	1 × 40 000	3 600
Martinez	Pacific Gas & Electric Co.	1 × 40 000	3 600
Oleum	Pacific Gas & Electric Co.	1 × 40 000	3 600
Twelfth Street	Virginia Electric Power Co.	1 × 40 000	3 600
Market Street	New Orleans Public Service Co.	1 × 37 500	3 600
West End	Cincinnati Gas & Electric Co.	1 × 35 000	3 600
John C. Weadcock	Consumers Power Co.	2 × 35 000	3 600
Atkinson	Georgia Power Co.	2 × 35 000	3 600
Bryce E. Morrow	Consumers Power Co.	1 × 35 000	3 600
Newcastle	Penn Power Co.	1 × 35 000	3 600
Seward	Penn Electric Co.	1 × 35 000	3 600
Walnut Street	Columbus Rly. Power & Light Co.	1 × 30 000	3 600
Millers Ford	Dayton Power Co.	1 × 25 000	3 600
Station No. 3	Rochester Gas & Electric Co.	1 × 25 000	3 600
Ottawa Street	Board of Water & Electric Light	1 × 25 000	3 600
Twin Branch	American Gas & Electric Co.	1 × 22 500	3 600
E. Wells Street	Milwaukee E. Rly. & Light Co.	1 × 13 700	3 600

One of the main advantages claimed for hydrogen cooling is that, due to the lower density of hydrogen, the windage losses of the machine are reduced to only about one-tenth of the value they would have in air. Also, as a result of the superior cooling properties of hydrogen, about 20 % greater output can be obtained with the same amount of active material for the same temperature-rise of the windings.

The size of the gas coolers of hydrogen-cooled machines is only a fraction of that of air coolers, and the hydrogen-cooled machine is quieter than the air-cooled machine, due to the virtual elimination of windage losses.

The main disadvantage associated with this method of cooling is the possibility of explosion, and it is necessary to take special care in connection with the seals on the generator shaft and all the interconnecting plant and pipework associated with the hydrogen side.

Operating experience in America has indicated that although hydrogen-cooled generators require at first more supervision than air-cooled generators, with increasing familiarity in the control of the various auxiliaries no greater operating difficulties are ultimately experienced than with air-cooled machines.

No hydrogen-cooled generators have been put forward so far in this country.

(b) Transformers

The core type of transformer with cylindrical limbs predominates, and the inherent weakness of the windings of transformers of this type against electromagnetic forces set up under short-circuit has been successfully overcome by bracing and the use of rigid materials for packing and spacing the windings.

There appears to be no difficulty in providing insulation for the highest voltages in commercial use, an interesting example being the 287·5-kV transformers on the Boulder Dam–Los Angeles lines, the voltage across each winding to the neutral being 166 kV. It is reported that even higher voltages are under trial in Germany and Russia.

Tanks of welded sheet-steel construction have superseded the cast and riveted designs, thus effecting considerable saving in weight and space.

The maximum capacity of transformers may be said to be limited rather by the facilities for transport than by the question of design.

Amongst the large transformers installed in this country may be cited the 93 750-kVA, 33/12·5-kV units at Barking and the 87 000- and 80 000-kVA, 66/11-kV units at Battersea.

Table 16

Large Power Transformers Installed or on Order in this Country

Station or substation	Undertaking	Number	Capacity	Voltage ratio
			kVA	kV
Barking	County of London E.S. Co.	4	93 750	33/12·5
Battersea	London Power Company	2	87 000	66/11
Battersea	London Power Company	5	80 000	66/11
Clarence Dock	Central Electricity Board	2	75 000	132/33
Fulham	Fulham Borough Council	3	75 000	70/11
Dunston	North-Eastern E.S. Co.	3	63 000	66/13
Sheffield	Sheffield Corporation	2	62 500	11·4/35·5
Portishead	Bristol Corporation	2	62 500	6·3/33
Dalmarnock	Central Electricity Board	2	60 000	132/20
Ironbridge	Central Electricity Board	4	60 000	132/33
Ocker Hill	Central Electricity Board	2	60 000	132/33
Barking	Central Electricity Board	4	60 000	66/33
Deptford	Central Electricity Board	2	60 000	132/22
Luton	Central Electricity Board	2	60 000	132/33
Dunston	Central Electricity Board	2	60 000	132/66
Barton	Central Electricity Board	2	60 000	132/33
Ferrybridge	Central Electricity Board	2	60 000	132/66/33
Battersea	Central Electricity Board	2	60 000	132/66
Willesden	Central Electricity Board	2	60 000	132/22
Portishead	Central Electricity Board	2	60 000	132/33
Northfleet	Central Electricity Board	1	60 000	132/22/33
Barking	Central Electricity Board	1	60 000	132/66/33
S.E.E.	Central Electricity Board	1	60 000	132/66
Barking	County of London E.S. Co.	3	50 000	33/66
Valley Rd.	County of London E.S. Co.	3	50 000	66/33
Bourneville	Central Electricity Board	2	45 000	132/11
Birkenhead	Central Electricity Board	1	45 000	132/33
Cardiff	Central Electricity Board	2	45 000	132/33
Brighton	Brighton Corporation	1	40 000	33/8

In Table 16 is given a list of some of the large transformers installed or on order in this country.

The requirements of the Central Electricity Board for the grid have resulted in the standardization of a few sizes—ranging from 15 000 to 60 000 kVA, transforming from 132 kV to 66 kV, 33 kV, and 11 kV.

One of the greatest changes in materials used in transformer construction has been the general adoption of paper insulation for the winding conductors, and of synthetic resin-impregnated paper, fabrics, and asbestos, for the supports and packings.

There has been some experience with the use of non-inflammable liquids in place of oil filling, chiefly in the United States, the advantages claimed being the elimination of oil-fire risks, absence of sludging or oxidation of the liquid, absence of action on transformer materials, greater mobility than oil, etc., and hence smaller and lighter transformers.

With regard to regulating apparatus, impetus has been given to the development of on-load tap-changing gear as a result of the decision of the Central Electricity Board to adopt this system on all their 132-kV transformers. It is generally agreed that tap-changing is best done on the high-tension windings and that the gear should be in a chamber located outside the main transformer tank.

(c) Switchgear

The establishment of testing stations where circuit-breakers can be tested under conditions simulating those of service, including short-circuits, whilst the conditions and performances are recorded by oscillographs, has made useful contributions to the knowledge of both designers and users of the apparatus, and has brought about modifications and improvements to oil-switch design.

The standard practice in this country is to use oil circuit-breakers, as it is generally recognized that some oil is necessary to secure extinction between the arcing contacts, but designers aim at keeping the oil volume as small as possible.

Neither in Great Britain nor in the United States is there any evident tendency to replace oil as an arc-extinguishing agent by compressed air, water vapour, etc. On the Continent there has been considerable development of compressed-air extinction.

In England the general trend has for years been in the direction of metal-clad gear, while on the Continent both indoor and outdoor equipments are largely of the open type.

For indoor installations of any magnitude it has been found necessary to divide the switchgear into several sections to avoid a large concentration of power on one set of busbars and to minimize the fire risk.

(8) HYDRO-ELECTRIC PLANTS

There have been some very interesting hydro-electric schemes put into commercial operation during the last 3 years in Scotland, and one such—at the instance of the Galloway Water Power Co.—may be briefly referred to as possessing some novel features.

Table 17

PARTICULARS OF HYDRO-ELECTRIC STATIONS OF THE GALLOWAY POWER COMPANY

Station	Head	Number of sets	Size of sets	Total capacity
	ft.		kW	kW
Kendoon ..	150	2	10 500	21 000
Carsfad ..	64	2	6 000	12 000
Earlstoun ..	65	2	6 000	12 000
Glenlee ..	365	2	12 000	25 000
		2	500	
Tongland ..	102	3	11 000	33 250
		1	250	
Total capacity ..	..	..	..	103 250

This comprises 5 power stations, and 7 reservoirs with the necessary dams, tunnels, aqueducts, and pipe lines. The total capacity of the power stations is 103 250 kW, made up as shown in Table 17.

Four of the stations—Kendoon, Carsfad, Earlstoun, and Tongland—are in series and are supplied from a reservoir which is an enlargement of Loch Doon. The fifth station—Glenlee—is supplied from an artificial lake and discharges along with water from Kendoon, Carsfad, and Earlstoun, to the Tongland station.

The whole scheme is designed for peak-load operation with a low load factor of about 20%, the intention being to operate the stations for an average of 6–8 hours per day in winter and 3–4 hours per day in summer. This enables the steam stations in central Scotland and north-east England to run at a uniform base load. It is understood that the cost of the civil engineering works was much less than it would have been if the plant had been designed for continuous operation.

During the year 1937 the 5 stations generated 200 million units and the sum of the maximum demands was 109 000 kW.

(9) FIRE AND AIR-RAID PRECAUTIONS

The protection of buildings and plant against fire risks has received considerable attention during the past few years. It has received particular impetus as a result of the recent activities in connection with air-raid precautions.

In the case of indoor-type main switchgear the tendency is to locate this in separate buildings or to divide it into sections with substantial walls between each, so as to reduce the risk of a fire spreading from one section to another.

Permanent installation of fire-fighting equipment is usually provided in every section of the plant where there is any likelihood of a fire occurring, arrangements being made for this to be brought into operation automatically in the event of an outbreak of fire. The apparatus is also so arranged that it can be operated from points external to the plant itself.

The most vulnerable points are, of course, the lubricating-oil tanks and equipment on the main turbines, the main generators, and the main switchgear.

Whilst there are a number of different forms of fire-fighting equipment and chemical extinguishers on the market, it appears that the types most favoured for large power-plant installations are the fine water spray (or Mulsifyre system) and those using CO_2 as an extinguishing agent.

In addition to the special fire-fighting equipments permanently installed at the most vulnerable points, it is usual to arrange water supply lines and hose connections at all parts of the power plant, and frequently this is augmented by portable trucks carrying foam fire-fighting equipment with the necessary flexible hoses, etc., as well as a number of hand-operated chemical extinguishers.

It is becoming a matter of importance to train men to form auxiliary fire-fighting squads for dealing with any contingencies that may possibly arise.

With the object of reducing fire risks to a minimum the present tendency is to endeavour to limit the amount of oil in circuit-breakers. The quantity of lubricating oil required for turbines cannot be substantially reduced, but the fire risk can be lessened by paying careful attention to the layout of the equipment, e.g., by grouping the oil pumps and purifiers, etc., as distant as possible from any high-temperature point and running the oil pipes as far away as possible from steam pipes, so that in the event of a leakage there is no tendency for the oil to be ignited.

Air-raid precautions have received particular attention recently, and it is appreciated that power stations and substations, being key points, may be liable to attack. The standard type of building—especially those utilizing glass to a very considerable degree—affords little or no protection, and the wholesale structural safeguarding of the main buildings of large power stations against a direct hit is out of the question. The most that can be done is to protect the buildings, plant, and operatives, against blast and splinters and against small incendiary or gas bombs.

The main chance of avoiding a direct hit is by " black-ing out" the station, and provision should be made in the form of screened or indirect lighting to enable a limited number of the essential instruments and plant to be kept under observation whilst giving no visible sign from above.

The protection of buildings against blast and splinters can be accomplished by erecting external walls to take the brunt of the impact, bricking up windows, substituting concrete for glass in all roof lights where the strength of the structural steelwork permits, or otherwise providing protection for such roof lights, etc. In the matter of plant, local protection of the most vulnerable portions can be obtained by the construction of temporary light steel structures reinforced with sandbags.

Protection for the key men in power stations can be provided in the form of sandbagged shelters or sheet-steel kiosks provided with small openings to enable observation to be kept on the instruments and plant.

It is sometimes stated that the construction of the grid has rendered electricity supply more vulnerable and liable to breakdown in the event of aerial attack, due to the concentration of generating plant in a smaller number of stations of larger individual capacity than would be the case if the grid did not exist.

This line of criticism overlooks the fact that the interconnection afforded by the grid is likely to ensure continuity of supply in the event of destruction of individual stations to a far greater extent than would be possible if each area of supply were dependent upon a single supply centre.

(10) GENERAL

It is not possible in a general review of this nature even to touch upon many items which might be included.

For example, the question of plant to be provided for peak-load or emergency operation is a subject sufficient in itself to merit a complete paper, but it is of interest to record that in the last few years a number of plants have been installed which have been specially designed for such emergency operation. The main feature of these installations is the speed with which they can be brought into service, and accounts of some recent plants in Norway, New Zealand, and Austria, indicate that these special steam plants can be brought up to pressure from cold in $3\frac{1}{2}$–5 minutes, the turbine brought up to speed in 20 minutes, and the whole equipment carrying full load within 25–30 minutes from cold starting conditions.

They are usually installed as emergency standby plant to take care of breakdown of hydro-electric plants.

The example at the Simmering station in Vienna is of interest since it comprises a high-pressure accumulator which is kept charged continuously and is of sufficient capacity to run the steam plant during the period which elapses between the initial failure and the bringing into service of the steam boiler.

A review of developments in power-station equipment over the last 3 years would be incomplete without reference to the fact that elimination of sulphur in the gases discharged from large power-station chimneys situated in residential areas has been successfully accomplished, as evidenced by the efficient and continuous operation of the large flue-gas washing plant installed at the Battersea and Fulham stations.

As to the future trends in the design of large base-load stations in this country, it appears probable that the steam conditions selected will be either 600 lb./sq. in. at 850° F. or 1 200–1 400 lb./sq. in. at 950–970° F., operating on the straight regenerative cycle.

Turbo-alternator capacities of 50 000 and 75 000 kW will be adopted with 100 000-kW units for the largest stations. The corresponding boiler units will have capacities of 300 000 to 500 000 lb./hour each, two boiler units being provided for each main set.

Considerations of air-raid precautions and peak-load requirements will necessitate keeping some of the older stations in service which under more normal conditions would have been closed down. If this condition is likely to persist it is possible that superimposition of extra-high-pressure plant, such as has been adopted by a large number of stations in the United States, may be considered with a view to increasing the efficiency of these older stations.

TELEPHONY AND TELEGRAPHY*

By W. G. RADLEY, Ph.D.(Eng.), Member.†

INTRODUCTION

Publication of the present review comes at a time when important changes are taking place in the art of speech transmission over long trunk telephone circuits. For new construction, cables containing several hundred conductors will be superseded by those permitting the transmission of frequencies up to 100 kc./sec. and higher, over a few conductors. These will be used as part of wide-band carrier telephone systems providing a large number of different speech channels over one pair of conductors. A coaxial cable between London and Birmingham, designed to provide 320 speech channels over each coaxial pair, comes within this category, as well as cables of more conventional design. A new type of amplifier capable of handling *en bloc* the whole of the frequency band transmitted over a pair of conductors, and technical improvements in the design of filter networks, have combined to make such systems commercially practicable.

In the near future the ease of setting up a long-distance connection will be increased as the signalling facilities existing in local areas are extended to the trunk network by the use of alternating currents in the voice-frequency range for the transmission of signals and dialling impulses. It will be possible for the operator at the originating trunk exchange to exercise complete supervision over a call and, in cases where it terminates in an automatic area, to build up the complete connection by dialling. In the immediate future the extent of this development in Great Britain will exceed that in any other country.

During the past few years there has also been a growing recognition by telephone engineers that the volume of the received sound is not the true criterion of the excellence of a telephone conversation. Increasing attention has been paid to the quality of the received speech. This tendency has directed experimental work towards the development of transmitters and receivers giving increased fidelity of reproduction over a wider frequency range than hitherto. Notable improvements have resulted in America, but they have not yet been fully absorbed into the public service owing to adverse economic conditions.

While the experimental work leading to the above developments has been taking place, the availability of the telephone in rural areas in Great Britain has been increased by the construction of small unattended automatic exchanges giving a 24-hour service. The conversion of city areas to automatic working is proceeding as manually operated exchanges reach the end of their economic life.

In the British telegraph service the period has been mostly one of consolidation, during which the extensive developments referred to in the previous review‡ have been brought into service throughout the whole country. Except for telegraphy to ships the use of the Morse Code has disappeared in Great Britain and, apart from minor local circuits worked by telephone methods, teleprinter working is universal. In other countries morse is in process of being displaced. International telegraphy over certain Atlantic cables has benefited by the application of a new multiplex system enabling higher signalling speeds to be obtained. Improvements in the terminal equipment have further reduced the delay in handling cable messages.

Following the practice adopted in previous reviews of progress dealing with this subject, Table 1 gives the mileage of telephone and telegraph wire in the principal countries of the world. It also shows the extent of telephone development in these countries.

TELEPHONY

Subscribers' Apparatus

Telephone receivers.

Moving-coil telephone receivers have been developed and, by comparison with normal moving-iron receivers, have a more extended frequency range over which the sensitivity is well maintained. They are, however, bulkier and heavier than moving-iron receivers, and generally less sensitive at frequencies below 3 000 cycles per sec. It does not appear likely that the latter will be displaced for general use, but improved types of moving-iron receiver have been designed and tested and are in production in the U.S.A., Germany, and Great Britain. The improvements have been effected in various different ways, but generally a more uniform sensitivity over the desired frequency range has been obtained by suitable adjustment of the natural frequencies and the extent of damping of the mechanical and acoustical resonances. Factory manufacture of the improved type was commenced 2 years ago in the U.S.A., and about 2 millions are probably now in service. In this country it is proposed to make use of the first supplies of the new receiver for special telephones, to be used in positions where the conditions are difficult.

Telephone transmitters.

There are no indications of any change from the carbon-granule type of telephone transmitter for general use. Improvements have been made in the detailed design of the inset form, used by the Post Office, chiefly to render it more immune to the deteriorating effects of moisture when used in public call-boxes and other places where the calling rate is high. Modern methods of measurement and improved laboratory apparatus have made possible a

---

* A review of progress.

† Post Office Engineering Department.

‡ B. S. COHEN: *Journal I.E.E.*, 1935, vol. 76, p. 169.

Table 1

TELEPHONE AND TELEGRAPH DEVELOPMENT OF VARIOUS COUNTRIES

	Australia	Belgium	Canada	Denmark	France	Germany	Gt. Britain and N. Ireland	Holland	Italy	Norway	Sweden	U.S.A.	
Miles of telephone wire	2 600 000*	1 918 000	5 197 000	1 353 000	5 603 000	16 470 000	13 150 000	1 220 000	1 660 000	655 000	2 580 000	90 500 000	Except for the U.S.A. the mileages given in this row are those existing at the beginning of 1937
Total length of junction and trunk circuits, miles		121 300†		167 000	1 197 000	1 495 000‡	795 000‡	201 600	241 500§	82 600§	517 500	8 080 000	The mileages given are those of circuits and not wires. The lengths of phantom and carrier-current circuits are included, but spares are not included
Percentage of total junction and trunk-circuit mileage contained in land and sea cables		88·8†		76·1	53·1	79·2‡	92·0‡	92·6	68·2§	14·5§	62·6	83·0	Land-cable mileage includes both underground and aerial cables
Number of telephones	579 567*	393 528†	1 266 228¶	425 951	1 552 618	3 623 697‡	3 050 012‡	401 484	568 279§	221 907§	738 698	19 450 331	
Telephones per 100 of population	8·5	4·7	11·4	11·2	3·7	5·3	6·5	4·6	1·3	7·7	11·8	15·3	
5 years' increase in number of telephones (1931–1936), per cent	18·8	19·5	– 7·4	14·6	20·6	9·3	34·3	17·3	—	8·6	22·6	– 6·0	The figure for France represents a 5¼-yr. increase, that for Norway a 4¼-yr. increase
Percentage of total number of telephones served by automatic exchanges	44·8*	64·4†	43·8	36·6	51·6	—	54·0‡	69·9	—	49·5§	36·2	43·7	
Number of telephone conversations per annum (in millions), 1936	514	294	2 449	665	941	2 562	1 983	—	—	253	985	26 800	Includes local and trunk calls and outgoing international calls
Miles of telegraph wire	104 000	35 000	357 000	7 500	319 000	166 000	255 000	12 000	272 000	23 000	19 000	2 285 000	The mileages given in this row are those existing at the beginning of 1937
Number of telegrams sent per annum (in millions), 1936	16·2	5·6	11·7	1·7	28·7	17·2	58·8	3·0	—	2·9	3·9	190	

The data given apply to 1st January, 1938, unless otherwise stated. They have been compiled mainly from *Europäischer Fernsprechdienst*, 1938, vol. 50, p. 406, etc., and "Telephone and Telegraph Statistics of the World" for 1937, published by the American Telephone and Telegraph Co.

* At 30th June, 1936. † At 1st March, 1938. ‡ At 31st March, 1938. § At 30th June, 1937. ¶ At 1st January, 1937.

considerable elucidation of the *modus operandi* of the carbon-granule transmitter. This new knowledge has already been put to practical use by the Bell System companies (in the U.S.A.), who have brought into service a redesigned telephone transmitter, used without a mouthpiece. Like the new receiver, this transmitter shows a marked improvement over earlier instruments as regards variation in sensitivity with change of frequency. The sensitivity is also less affected by change of position with respect to the mouth.

Methods of connection, etc.

The new telephone transmitters and receivers referred to have been designed for incorporation in the combined hand-set, or hand microtelephone, which is becoming normal equipment. In the construction of such equipment the period has been marked by a considerable increase in the extent to which plastic mouldings have been employed to simplify design, and to reduce overall size. As in other items of subscribers' equipment, there is a tendency to make greater use than before of newly developed magnetic materials, including high-permeability alloys, typified by Permalloy and Permandur, and the cobalt and aluminium-nickel-cobalt series of permanent-magnet alloys. These materials give not only improved performance but also reduced size.

An important development on both sides of the Atlantic has been the introduction of an anti-side-tone method of connection of the transmitter and receiver as standard for new telephone sets, i.e. connection in such a way that there is a reduction in the loudness of the talking subscriber's own speech as heard by himself. The advantages to be gained from this method of connection were realized in this country and in America prior to 1935. Together with the substitution of older-type transmitters and receivers by those with improved characteristics, it has resulted in very considerable improvement in the quality of speech transmission. The anti-side-tone circuit affords especial advantage in the presence of room and traffic noises, commonly met with in call-office working, and is used for the equipment installed in the new telephone kiosks designed by Sir Giles Scott and introduced by the Post Office.

Increased efficiency of apparatus has made possible the use of cables containing conductors as small as 10 and 6½ lb. per mile for connecting subscribers to the exchange.

Loud-speaking telephones, etc.

In this country considerable progress has been made in the development of the loud-speaking telephone for use in place of the ordinary hand-set. Trials with a rather expensive type of equipment comprising a distant-pick-up microphone and loud-speaker have shown that a satisfactory service can be obtained when the apparatus is installed in a reasonably quiet office. The equipment includes an interesting example of a voice-operated switching system utilizing rectifier attenuation networks as switches.* The switching provides that the circuit is only open to speech in one direction at a time, and thus prevents interaction between the loud-speaker and the microphone. A "break in" facility is also provided so that incoming speech can obtain control of switches that are operated in the reverse direction. The design of the equipment has recently been simplified, giving a substantial reduction in cost while retaining the existing facilities.

Deaf-aid equipment, comprising an amplifier for use with a normal telephone receiver, has been the subject of further improvement.

Methods of Interconnection

During the past 4 years, automatic telephone exchanges have been steadily replacing manual types, with benefit to the service given to the subscriber, especially at night. At the end of September, 1937, there were 2 355 automatic exchanges in the United Kingdom and 3 366 manual exchanges, serving respectively 1 516 349 and 1 386 079 stations. This represents an increase of 56 % in the number of automatic exchanges during the period under review.

Exchange apparatus and systems.

Side by side with progressive automatization, considerable progress has been made by the Post Office towards the use of apparatus of simplified and standardized design. The *3 000 Type* relay, embodying many of the best features of pre-existing types, was standardized some 4–5 years ago. A simplified design, the *600 Type*, with limited capacity, followed in 1935. Somewhat similar standardization of designs conforming fairly closely to earlier American types is taking place within the Bell Telephone System. On both sides of the Atlantic twin contacts are being used. Silver has been adopted by the Post Office as a general-purpose contact material, while American practice favours the more general use of palladium.

Close co-operation between the Post Office and the British manufacturers of telephone apparatus has resulted in the design of a 2-motion selector, known as the *2 000 Type* switch, which is cheaper and lighter than any of the five different types hitherto used, and occupies less space on the racks. The first main exchange utilizing the new equipment was opened at Rugby in October, 1936, and *2 000 Type* equipment will be standardized for all new exchanges. The electrical circuits associated with the switch have been redesigned and a balanced method introduced of applying supervisory tones to the line. This will render the tone less likely to be overheard on other circuits. Construction of unit types of automatic exchange has proceeded in the less densely populated areas in Great Britain. Types having ultimate capacities of 100, 200, and 800 lines have been standardized.

The cross-bar system.

Development of the "cross-bar" switch in the U.S.A. has made possible the construction of automatic exchanges operating on principles similar to that developed by Betulander in Europe. By means of relay-like operations the switch enables connections to be made and held at will at any co-ordinate point in an array of fixed and moving contacts wired together to form vertical and horizontal multiples. The first American exchange of this type was opened in Brooklyn at the end of 1937, with an initial capacity of 1 600 lines, and a 10 000-line exchange of the same type is under construction in New York City. Cross-bar-type exchanges are anticipated to give improved service with less maintenance and require a shorter installation period than the panel-type equipment used in the largest American cities.

---

* L. E. RYALL: "A New Subscribers' Loud-speaking Telephone," *Post Office Electrical Engineers' Journal*, 1936, vol. 29, p. 6.

Supervisory tones and verbal announcements.

An inductor-type alternator having separate windings to give better quality " dial," " ringing ," and " busy " tones has been developed. Another development has been the experimental replacement since April, 1935, of the " busy " tone by verbal announcement of the word " engaged " in the Folkestone area. Observations show that the change has resulted in a reduction in holding time and in the number of " confirmation calls," and the experiment is being extended to the Reading and Maidstone areas. The announcement is given by means of a photo-electric equipment utilizing a sound film mounted on a continuously rotating drum.*

Extension of subscriber dialling areas.

Provision is to be made for all calls of less than 15 miles in Great Britain to be dialled by subscribers without calling in an operator. This necessitates the provision of equipment for automatic discrimination and for registration on the subscriber's meter of the charges for calls costing up to 4 times the normal penny fee. As a result of transmission over a number of junction circuits interconnecting intermediate exchanges, the dialling impulses may suffer such distortion that they can no longer be depended upon to step correctly the selecting switches. This problem has been intensively studied, and appears likely to be met by the use of a device known as a mechanical regenerator. This accepts and stores incoming impulses in such a way that they control the subsequent sending-forward of corresponding trains of reformed impulses. Work is well advanced which will make possible the incorporation of such devices in the relay sets in various types of automatic exchange.

Junction signalling and dialling.

Dialling by the usual methods of automatic telephony cannot be accomplished over circuits where the resistance exceeds about 1 500 ohms. For longer junction circuits, however, increasing use is being made of cables containing light-gauge conductors and equipped with amplifiers. Experimental work in the Post Office laboratories has resulted in a system† which will give signalling and dialling facilities over such circuits up to 4 400 ohms loop resistance, corresponding roughly to 100 miles of 20 lb. per mile star-quad cable. Direct-current pulses are transmitted over the phantom circuit, but the received signal shape is improved by use of the principle of the inductive shunt. The more sharply defined pulses resulting are impressed on the grid of a pentode valve and control the operation of a polarized relay in the anode circuit. It has been found necessary to dissociate all incidental equipment from the line during the dialling period. This necessitates storage of impulses at the outgoing end in the mechanical regenerator previously referred to, while a pre-dialling signal is being sent.

Signalling on trunk circuits.

Very great changes are impending in the methods of signalling over repeatered trunk circuits. Replacement of voice-frequency ringing methods by systems utilizing voice-frequency currents to give automatic signalling and dialling facilities was anticipated in the 1935 review. Development in Great Britain has taken place in advance of that elsewhere, and the introduction of voice-frequency signalling and dialling between many of the zone centres in this country is planned for 1939. The frequencies to be employed, 600 and 750 cycles per sec., are those standardized by the C.C.I.F.* for signalling and dialling over international circuits, and the signals necessary to cause the automatic switching operations use coded pulses of current at one or other of these frequencies. Dialling is accomplished by sending pulses of current at 750 cycles per sec. One of the most difficult problems involved is that of making a signal receiver which has to respond to signalling frequencies of widely varying intensities when they represent signals and yet be immune to operation by the same frequencies when they occur in speech. In principle such receivers comprise a tuned detector circuit, responding to the signalling frequencies, and a guard circuit operated by speech currents of selected non-signal frequency. When operated, the guard circuit prevents any signal being given by the detector circuit. This can be ensured either by relay operation or by the application of blocking negative bias to the grids of the signalling valves, as in the case of the British receiver. This receiver utilizes three valves, the first of which operates on a development of the overloaded-amplifier principle and will keep the output to succeeding stages constant despite a wide variation of input level. Following selection of the signalling frequencies, two valves, operating on the well-known rectified reaction principle, control respectively the response of anode-circuit relays to currents at 600 and 750 cycles per sec.† 3 906 of these receivers are being installed in connection with the immediate conversion programme of the British Post Office. They take all their power supply from the 50-volt exchange battery, and with permissible variations in the battery voltage and other conditions will operate satisfactorily with incoming signals varying in level over a range of 25 db.

Holland has equipped many lines for voice-frequency signalling and dialling by utilizing the non-standard frequency of 2 400 cycles per sec. for the purpose. Trunk circuits between several Italian cities are being operated with voice-frequency signalling, while considerable developments along the same lines are likely in Germany. British contractors are utilizing the frequencies of 600 and 750 cycles per sec. for signalling and dialling over trunk lines in the Irish Free State and in Australia.

Current of a frequency of 50 cycles per sec. is being used for transmitting dialling impulses over fairly long circuits in Switzerland and in South Africa. It is not likely, however, that such a system will find application in Great Britain.

---

* H. Williams and W. A. Hibberd: "The Replacement of 'Busy' Tone by Verbal Announcement," *Post Office Electrical Engineers' Journal*, 1935, vol. 28, p. 208.

† W. H. B. Cooper: "Differentiated Impulse System of Dialling over Long Junctions," *ibid.*, 1938, vol. 31, p. 108

* Comité Consultatif International Téléphonique.

† T. H. Flowers and B. M. Hadfield: "Voice-frequency Signalling on Trunk Circuits," Institution of Post Office Electrical Engineers, Professional Paper No. 162.

An interesting innovation, the *Tarifeur*, was put into use in December, 1936, on the Bruges–Blankenberghe circuit. This registers automatically on a ticket the particulars which under manual working are noted by the telephonist. It is likely, however, that trunk calls will be handled by operators at the originating trunk exchange for very many years to come. Telephone engineers are envisaging the time when such operators will be able, without assistance, to obtain a wanted subscriber in another country by dialling over international lines. Tentative decisions have already been taken by the C.C.I.F. with regard to the code of signals for such a purpose.

Wire Transmission

Voice-frequency circuits.

The rapid growth of the British trunk network is shown by Table 2.

Apart from recent construction, the majority of the British trunk circuits are provided by voice-frequency 4-wire circuits in coil-loaded underground cables. Provision of zero-attenuation circuits between zone centres, referred to as a notable development in 1935, has continued, and 1 682 echo-suppressors have been installed in this connection. Improved equipment has been introduced to economize time spent on carrying out routine measurements, and enables simple a.c. measurements to be made from positions in the exchange previously restricted to d.c. testing. This has involved development of stable single-frequency oscillators having automatically controlled outputs, and these are used in conjunction with stable amplifier-detectors which operate with d.c. voltmeters for overall-loss measurements. The testing equipment has been developed with particular regard to constancy of performance. For more precise measurements and for fault location there have been developed a stable, uniform-output, oscillator having a frequency range of 30 to 16 000 cycles per sec. controlled by a single dial, and a direct-reading level-measuring set. Considerable advances in testing technique and apparatus have also been made abroad, particularly in America and Germany.

Table 2

	Circuits longer than 25 miles	Circuits longer than 200 miles
At 1st October, 1934 ..	4 136	69
At 1st October, 1935 ..	4 719	109
At 1st October, 1936 ..	5 367	159
At 1st October, 1937 ..	5 820	209

Some improvements have been made in the materials used for loading-coil cores, and in America a molybdenum permalloy is now being utilized which results in coils of smaller size and lower cost.

Application of carrier-frequency working to lines previously worked solely as voice-frequency circuits.

Carrier telephone systems over open wires were in extensive service in the U.S.A. as far back as 1931. Standard systems now yield up to 16 circuits for each pair of wires, different carrier frequencies being used for the channels forming the "go" and "return" paths of each circuit. The highest frequency used is 140 kc./sec. Corresponding development in Great Britain was cramped, since open-wire lines were relatively short and contained many underground-cable sections. Comparatively cheap equipment* using a carrier frequency of 6·5 kc./sec. has been developed and gives an additional speech circuit to meet seasonal traffic requirements, etc.

Recent study of the conditions governing the use of carrier telephony in cables has shown that it is commercially possible to use for this purpose selected pairs in many existing cables designed solely for transmission of voice frequencies. Transmission is only possible over non-loaded or very lightly loaded pairs, which have to be so spaced within the cable that they experience the minimum amount of mutual interference. Use of lightly loaded or non-loaded pairs, however, increases the transmission velocity of the circuit, which may reach 120 000 miles per sec. This is 5 or 6 times greater than that of cables loaded for working in the voice-frequency range only, and ample for telephoning satisfactorily over any distances possible on this planet. Attenuation at the higher frequencies usually fixes the maximum spacing of repeater stations. A system giving 4 carrier channels with 16 kc./sec. as the highest transmitted frequency has been developed by the Post Office† as a means of obtaining additional circuits from existing cables. This was applied to pairs loaded with 6-mH coils, spaced at 1 000-yard intervals, in the Liverpool–Glasgow cable after a single-channel carrier system had been successfully worked over other pairs in the same cable.

In the U.S.A. some existing cables have been adapted to 12-circuit working using a maximum carrier frequency of 60 kc./sec. Whereas with 4-circuit working it is possible to include "go" and "return" channels in one cable, the near-end cross-talk between circuits transmitting in opposite directions makes this impossible with the higher carrier frequencies employed for the 12-circuit system.

Systems designed for carrier-frequency working.

(i) *Multi-quad cables.*—The Bristol–Plymouth 12-circuit carrier system, opened to service at the end of 1936, was the first of a number of such systems working over specially designed cables. The equipment on this route has recently been described to The Institution.‡ Paired cables were used, i.e. the pairs were not twisted together to form quads, as is usual in voice-frequency cables, and "go" and "return" channels were segregated to separate cables. The highest carrier frequency used is 60 kc./sec., and the system provides 228 telephone circuits over two cables, each containing 19 pairs of wires.

As a result of the success obtained with the Bristol–

---

* R. J. Halsey: "Recent Advances in Carrier Telephony," Institution of Post Office Electrical Engineers, Professional Paper No. 157.

† R. J. Halsey and D. P. M. Millar: "Carrier System No. 4," *Post Office Electrical Engineers' Journal*, 1936, vol. 29, p. 226.

‡ A. S. Angwin and R. A. Mack: "Modern Methods of Multi-channel Telephony on Cables," *Journal I.E E.*, 1937, vol. 81, p. 573.

Plymouth installation, other cables designed for 12-circuit working were rapidly laid and this will be a premier means of providing future long-distance circuits in this country. Cables have already been provided for 15 routes with a route mileage of 1 696 and, when fully equipped, will provide 288 circuits on each route. The use of separate " go " and " return " cables of the star-quad type, but having 12 quads (groups of 4 conductors) in the space previously occupied by 19 quads, has been standardized. The conductor weight is 40 lb. per mile. Development of multi-quad cables for this purpose has required more accurate manufacturing processes, and increased spacing both between the conductors and between the conductors and the sheath. Different lays have to be adopted for each quad, in order to reduce mutual electromagnetic coupling. Reduction of the remaining cross-talk to negligible proportions can only be obtained by auxiliary balancing networks.

(ii) *Coaxial cables.*—The structure formed by a pair of concentric or coaxial conductors was the subject of much theoretical study by prominent mathematical physicists during the latter half of the nineteenth century. Use of such a structure for long-distance transmission of telecommunication signals extending over a wide frequency-band dates, however, from experiments carried out at Phoenixville, U.S.A., in 1933. The experiments showed that it was possible to transmit a frequency band, about 4 Mc./sec. wide, over a circuit comprising a copper wire supported along the axis of a copper tube of about ½ in. internal diameter, in such a way that the majority of the dielectric was air. The first cable based on the new principles to be laid in this country has already been described in the *Journal.** The cable contains 4 tubes within an outer lead sheath 1·74 in. in diameter. Two of these tubes are to provide respectively the " go " and " return " paths for 320 carrier telephone circuits utilizing carrier frequencies spaced at 5 000 cycles per sec. intervals between 0·5 and 2·1 Mc./sec. The other two tubes are reserved for the possible future transmission of television programmes requiring a wide frequency band. The original cable was laid between London and Birmingham, and is being extended to Newcastle via Manchester and Leeds, making a total of 344 route miles for the British coaxial-cable system. Other coaxial cables have been laid between New York and Philadelphia and between Berlin and Leipzig. Both are 2-tube systems, the American being designed for 240 simultaneous 2-way telephone conversations, utilizing a frequency band up to 1 Mc./sec. The terminal equipment and repeaters at present associated in the German equipment only permit working over a frequency band between 0·8 and 1·3 Mc./sec. Other similar cables are projected or being laid in Germany.

Filters for carrier telephone systems.

The filters at present used at the terminal stations of 12-channel systems in this country are of conventional design electrically, consisting of inductance coils and condensers. For corresponding American systems, the piezo-electric coupling between electrical and mechanical oscillations of quartz-crystal plates has been used to provide the equivalent of inductive reactances with much lower losses than can be obtained by the use of inductance coils. In both countries, quartz-crystal plates form an integral part of the channel filters in the coaxial-cable system.

Repeaters.

Development of multi-circuit carrier and wide-band coaxial systems would not have been economically practicable but for the development by Black* of an amplifier capable of handling a wide band of frequencies without giving rise to interference between components at different frequencies. Such an amplifier finds its application at intermediate repeater stations, where the whole of the frequency spectrum is dealt with by one amplifier without the necessity of separating the channels. The principle of negative feed-back is employed, and the distortion of the amplifier is reduced proportionately with the reduction of gain. Equalization of the overall circuit loss over a wide frequency band is possible by giving to the feed-back circuit a frequency characteristic of the same shape as that of the line to be equalized. Proportionate improvement in constancy of amplification with variations in power-supply voltage is also effected.

On the British 12-circuit cable system the maximum repeater spacing is 18 miles. Increased attenuation of the higher frequencies makes closer spacing than this necessary with a wide-band system, and on the London–Birmingham coaxial cable the average distance between repeaters is about 7 miles. The majority of the repeater stations are unattended, their control and maintenance being effected from the main stations and provision being made for the automatic bringing-into-circuit of a spare repeater should the working repeater fail. The power supply required by the valves is fed over the coaxial cable as 50-cycle current from the main stations without interference to the transmission of " intelligence." At the highest transmitted frequency the total attenuation of a typical section between repeaters is of the order of 50 db.; and the gain/frequency characteristic of the equalized circuit (cable and repeaters) is flat within about ± 3 db. over the whole transmitted frequency band—from 0·5 to 2·1 Mc./sec.

International Telephony

Submarine cables.

A telephone service between Australia and Tasmania was inaugurated in March, 1935, utilizing a recently laid submarine cable of a type employing a single, non-loaded, central conductor and coaxial return. The dielectric material was para-gutta (a mixture of de-proteinized rubber, de-resinated balata, and wax). An intermediate repeater station was possible on King Island, and negative-feed-back amplifiers were used for the first time in commercial practice. Six telephone circuits and a music programme circuit together with telegraph facilities are provided by carrier-frequency channels.

Two submarine cables of similar coaxial type were laid between Aldeburgh and Domberg (Holland) in 1937. Normally they will provide respectively the " go " and " return " paths for 16 telephone circuits, the maximum

---

[*] A. S. Angwin and R. A. Mack: *loc. cit.* For further details see A. H. Mumford: "The London–Birmingham Coaxial Cable System," *Post Office Electrical Engineers' Journal*, 1937, vol. 30, p. 206.

[*] H. S. Black: "Negative Feed-back Amplifiers," *Electrical Engineering*, 1934, vol. 53, p. 114.

carrier frequency being 60 kc./sec. Similar cables were also laid in 1937 across the North Channel between Portpatrick (Scotland) and Donaghadee (N. Ireland). Another was laid in 1937 between Nevin (Wales) and Howth (Irish Free State), and one from Dartmouth to Jersey in 1938. Owing to the short length of the North Channel cables (21 nautical miles) the overall attenuation is lower than in the case of the Dutch cables, so that, although they are only equipped at present for 20 circuits, it is anticipated that it will be possible to add higher carrier-frequency channels to give ultimately a maximum of 100 telephone circuits. In the case of the cables laid singly, Nevin–Howth and Dartmouth–Jersey, the transmitted frequency band is divided between a group of 3 " go " and 3 " return " channels.

Radio links.

Progress in radio communication is reviewed elsewhere, but it may be of interest to note that, by means of a radio link, public telephone service between this country and Japan was opened in March, 1935. Service via a radio link with Iceland was commenced in August, 1935, and with Kenya in March, 1936. The wavelengths employed are 15·86 metres, Japan; 24·52 metres, Iceland; and 15·28 metres, Kenya. An improved 5-band privacy system designed to enhance still further the privacy of 2-way radio telephony was introduced in 1935 on the original long-wave radio circuit between London and New York. Considerable improvements, involving single-sideband working, have been made to the short-wave transatlantic circuits.

Utilization of ultra-short-wave radio links (1–10 metre band) for joining up telephone networks separated by sea channels is of comparatively recent origin, the first circuit to be employed on commercial traffic in Great Britain having been brought into service in 1932. A progressive policy is being maintained by the Post Office, covering use of such means to extend the telephone service to the Scilly Isles and outlying Scottish Islands, including the Hebrides, Orkneys, and Shetlands. Telephone service to the Channel Islands has been improved by the installation of four ultra-short-wave radio-telephone circuits, and to Northern Ireland by the addition in 1937 of a 9-circuit ultra-short-wave system to the 6-circuit system operating across the North Channel since 1935. The new North Channel system utilizes a radio carrier frequency of 76 Mc./sec. in one direction and 83 Mc./sec. in the other. It represents an important advance in technique in that the nine telephone channels are provided on the one radio carrier in each direction. Optical visibility exists between the two terminal stations, the equipment at which is designed for unattended operation and is capable of remote control from the nearest telephone exchange.

Protection against power circuits.

A revised edition of the " Directives " relating to the protection of telecommunication lines against the interfering effects of power systems has been prepared by the C.C.I.F. in collaboration with representatives of various international organizations representing electric traction, generation and distribution, and similar heavy-current electrical engineering interests. Research work which has thrown much light on the electromagnetic coupling between two lines, the screening effects of cable sheaths, and the distribution of disturbing harmonic currents in power-system networks, has been taken into account. Consideration also continues to be given to the problem of mitigating the damage done to cable sheaths by chemical corrosion and the electrolytic action of stray currents.

Special Services

The period under review has been remarkable for the popularity of services made available to the telephone subscriber by the aid of photo-electric talking machines. 340 000 calls for time are made every week in London, where a subscriber dialling the code TIM or asking for the time is routed to the " speaking clock."[*] The mechanism used to give a time announcement correct to ±0·1 sec. has already been described to The Institution. This service was opened in London in 1936 and was extended in 1938 to Edinburgh, Manchester, Glasgow, Birmingham, Leeds, and Bristol, trunk lines being used to feed the speech from the London clock. Clocks of somewhat similar design have been giving a remunerative service in many Scandinavian cities, and in Warsaw, since 1934. A different type of mechanism utilizing photo-electric reproduction from sound track printed on paper strip carried by an opaque drum is used to give a time service in France.

A simpler form of photo-electric talking machine was put into service in Stockholm in June, 1936, for the purpose of giving weather forecasts, and others of similar design have since been constructed.

TELEGRAPHY

Inland Public Services

Voice-frequency multi-channel working.

Conversion of the main inland routes in this country to voice-frequency telegraph systems working over the telephone cable network commenced in 1932, and there are at present 105 such systems installed, comprising 1 476 duplex channels. The features and advantages of the system were described in the last review. To extend the advantages to minor routes which do not justify the provision of the 12- or 18-channel main-line system, a smaller (4-channel) duplex system was introduced in 1935.[†] The equipment operates on a 2-wire repeatered or non-repeatered circuit having up to 18 db. attenuation, the carrier frequencies being 420, 660, 900, and 1 140 cycles per sec. in one direction and 1 380, 1 620, 1 860, and 2 100 cycles per sec. in the other. The equipment is made for either battery or all-mains supply, being normally all-mains at a small " out " office and battery at the central office. There are 12 such systems in use at the present time.

Ancillary working.

Expansion of about 40 per cent in the traffic following the reduction of charges for Post Office telegrams in 1935 led to the desirability of converting to teleprinter working a large number of circuits over which telegrams had been telephoned. A system of ancillary working has been devised* to facilitate staffing requirements at centres from which radiate a number of these lightly loaded circuits. The condition of the outgoing lines and teleprinter positions are indicated separately on specially designed switchboards, and means are provided for connecting any line to any teleprinter position. The latter are equipped with "answer back" units, which are arranged to transmit automatically the code of the office so as to save time in establishing and checking a connection. There are 25 ancillary systems now in use, comprising 520 circuits. Nearly 200 of these were previously telephone-telegram circuits.

---

[*] E. A. Speight and O. W. Gill: *Journal I.E.E.*, 1937, vol. 80, p. 493.

[†] L. W. A. Mitchell: "A 4-channel Duplex Voice-frequency Telegraph System," *Post Office Electrical Engineers' Journal*, 1935, vol. 28, p. 182.

Use of radio links.

Communication between the Scilly Islands and the mainland was improved early in 1938 by the opening of two short-wave radio circuits. Teleprinters are worked over one of these, and provide the first instance of teleprinters being commercially worked over a radio circuit in this country. A German invention—the Siemens-Hell writer—has been developed in that country for use on radio circuits which are subject to more interference than can be tolerated on a normal teleprinter circuit. The transmitter consists of a keyboard controlling cams specially shaped to produce impulses giving a facsimile reproduction of the letter in a simplified form of picture telegraph receiver. Irregularity in the received copy results if there is excessive interference, but the character is not rendered illegible.† To meet the requirements of a cheap system for the transmission of telegrams to and from such places as the Scottish islands, a radio-phonogram equipment consisting essentially of a simple transmitter-receiver providing telephonic communication in one direction only at a time has been developed.

Telex.‡

Provision of this service, in which a subscriber is provided with a teleprinter and can then exchange typewritten communications with any other subscriber similarly equipped, was referred to in the last review. The British service was originally operated on a frequency of 300 cycles per sec., but a change-over to 1 500 cycles per sec. was made in the latter part of 1936 in order to line up with international agreement and to secure advantages which the higher frequency has over the lower. There are about 380 installations in this country. The associated "printergram" service, whereby the subscriber has direct communication with a telegraph office for the transmission and reception of other telegrams by teleprinter, necessitates the handling of an average of 7 500 incoming and 20 000 outgoing messages per week at the 32 printergram positions in the Central Telegraph Office.

The Bell System operate a somewhat similar "teletypewriter" exchange service in the U.S.A. The American system was developed on the basis of the sole means of communication with the exchange operators being by means of typed characters. (In the British system the connection is set up by ordinary telephone methods.) There are now between 11 000 and 12 000 subscribers. The average time to effect connection for the whole U.S.A. is only 1·3 minutes. Owing to the number of links involved in very long connections, regenerative repeaters have been found to be necessary.

Automatic interconnection of lines.

On their landline system in the U.S.A. the Western Union Telegraph Co. have introduced a system which eliminates manual re-transmission of telegrams at central offices. Incoming messages are received on a printer re-perforator, associated with which is a switchboard cord circuit including a transmitter. By plugging into the appropriate jack indicated by the message designation the switchboard operators send all messages to a storage point, where they are queued and subsequently re-transmitted to line without further manual attention.

An important future development is likely to consist in the application of the methods of automatic telephony to public telegraph circuits, entirely eliminating the present re-transmission of telegrams at what would then become switching centres. A complete switching system would enable a through connection to be set up between any two offices in the British Isles by dialling the appropriate code. Increased circuit provision is necessary, however, since under the switched system chance traffic replaces the queued traffic inherent in the present re-transmission system. An automatic switching system has been developed in Great Britain and has successfully passed the test of a field trial involving 22 stations. It has been designed so that messages may be received on an unattended teleprinter and also so that, in the event of all extension circuits to the required office being busy, the message is passed to operators at the final switching centre for subsequent re-transmission.*

Instruments and maintenance.

Increasing use of teleprinters is being made by most telegraph administrations, and novel types have been designed. This has led to the development of improved testing methods both for the apparatus and for the line to which it is connected. Routine testing of telegraph circuits in Great Britain was introduced when voice-frequency working over the telephone cable network was started. More recently, teleprinter "margin" testers† have been designed and provided at all maintenance and overhaul centres. In the measurement of speed, which plays an important part in the correct functioning of telegraph equipment, considerable improvements have been obtained by the introduction of a piece of apparatus called a synchroscope.‡ In this instrument the accepted standard of speed or frequency is the frequency-controlled a.c. mains supply. For cases where this is not available, a stable, valve-maintained, tuning-fork oscillator has been designed.

Private-wire Services

Prior to the advent of the teleprinter, the main users of private telegraph services were the cable companies and Press interests. With the introduction of the teleprinter, however, increasing numbers of "private wires" have been rented to business houses, and this service is becoming of increasing relative importance. 900 private-wire circuits are now rented from the Post Office. A development of the private point-to-point communication to one in which a central office can communicate simultaneously with a number of others, includes some 8 systems and 130 stations.

---

* S. G. Lewis and C. E. Easterling: "The Teleprinter Ancillary," *ibid.*, 1936, vol. 29, p. 119.

† H. Stahl: "The Siemens-Hell Writer," *Telegraphen und Fernsprech-Technik*, 1933, vol. 22, p. 291.

‡ Teleprinter exchange service.

* L. H. Harris: "Automatic Teleprinter Switching," *Post Office Electrical Engineers' Journal*, 1936, vol. 29, p. 217.

† L. H. Harris, E. H. Jolley, and F. O. Morrell: "Recent Developments in Telegraph Transmission and their Application to the British Telegraph Service," *Journal I.E.E.*, 1937, vol. 80, p. 237.

‡ *Ibid.*

A system has been developed in America whereby a long-distance circuit is shared between a number of subscribers, each of whom has private-wire facilities in that the sender may start at any moment without the necessity of demanding a connection. The system is a development of the multiplex method of working, i.e. circuit use is divided between a number of terminations on a time basis. The cyclic period, however, is equally apportioned between the subscribers actually sending, so that, with only one subscriber sending on a channel, the speed is equal to that of the channel. A typical example of this is the division of 4 full channels into 48 " varioplex " sub-channels. The system is in use between New York and San Francisco, New York and Los Angeles, and on several other routes. Service is automatically metered and charged for on a word basis.

International and Long-distance Services

Continental services.

A 12-channel voice-frequency system, London–Paris, was opened in 1936; and another system, London–Brussels, in 1937. There are two London–Rotterdam super-audio channels (carrier frequency 2 940 cycles per sec.) superposed on the London–Hamburg and London–Stockholm telephone circuits.

Telex communication with foreign countries has recently been introduced, and at the present time facilities are provided for communication with Holland, Belgium, Germany, and Switzerland. Trials are being made with other European countries.

Submarine cables.

No new transoceanic telegraph cables have been laid during the period under review, but the Western Union Telegraph Co. have been experimenting with a submarine plough which, in shallow waters, can be used to make a furrow in the bottom of the ocean, feed the cable into it, and cover it up. Cables laid in this way will be protected against the heavy drags attached to the nets of steam trawlers which now cause extensive and recurrent damage in the fishing areas.

Improvements have been made in the design of valve amplifiers for submarine cables, resulting in greater stability and reduced susceptibility to the effects of earth currents.

Cables and Wireless, Ltd., have introduced machines which enable typed paper tape to be produced under the direct control of incoming morse signals, without the necessity for an intermediate stage involving perforation of a tape. The problem facing the designers was more difficult than those associated with teleprinting, since it was necessary to cater for a code in which the characters vary between 2 and 7 elements. The Western Union Co. have made progress in the application of the 5-unit multiplex system to non-loaded Atlantic cables, and have attained higher letter speeds with this system than can be achieved with 3-element cable code. Page printers have displaced tape printers on many of the cables operated by this system, reducing the terminal delay due to message-handling. A message-form ejector, incorporated in the printer, operates on a character designating the end of the message, and automatically moves a new form into the correct printing position.

Considerable experience has been gained in the use of storing transmitters and channel switching systems enabling particular channels of multiplex-operated cables to be extended to, or served by, landline outlets in any order made desirable by traffic requirements.

RADIO-TELEGRAPHY AND RADIO-TELEPHONY*

By C. E. RICKARD, O.B.E., Member.†

CONTENTS

(1) Foreword.
(2) International Regulations.
(3) Marine Services.
    Improved stability.
    Coast stations.
    Telephony.
    Trawlers and small ships.
    Express steamer equipment.
    Interference with radio on board ship.
(4) Direction-Finding Services.
    Adcock direction-finders.
    Mobile installations.
    Cathode-ray methods.
    Equi-signal beacons.
    Maritime radio beacons.
    Beacon equipments.
(5) Aeronautical Communications.
    Aircraft direction-finding.
    Intercontinental flying.
(6) Long-Distance Telegraph Circuits.
    Minimum-delay circuits.
    Printing telegraphy.
    Reduction of fading.
    Miscellaneous.
(7) Long-Distance Telephone Circuits.
    Short-wave telephone reception.
    Miscellaneous.
(8) Ultra-Short-Wave Circuits.
(9) Military Equipment.
    Medium-power pack sets.
    Small-power man-pack sets.
    Tank sets.
(10) Research and Development.
    Ionospheric investigations.
    Constitution of the ionosphere.
    Magnetic storms and sudden fades.
    Transmission theory.
    Frequency control.
    Adcock direction-finder.
    Signal-measurement apparatus.
    Commercial-service receivers.
    Vacuum tubes.
    Electron multiplication.
    Beam valves.
    High-frequency cables.
    Insulating materials.
(11) Acknowledgments.

(1) FOREWORD

In compiling a review of progress of radio-telegraphy and radio-telephony during the past few years, which have been notable for steady advance rather than outstanding invention, one is faced with two main problems: (1) where to start and where to finish, in relating such progress as should be recorded; and (2) what relative importance should be given to the numerous branches and ramifications which go to make up the science, art, and practice, which form the subject matter of such a review.

Progress in the science of radio may be held to cover advance of knowledge in theory and technique, but progress in the art, while dependent upon progress in the science, also depends for its practice to a large extent upon the commercial application of such improvements as may have been made in the past. Further, the commercial aspect of progress in the art of radio, though mainly controlled by economics, is also governed by the application of international regulations in the practice of radio communication.

As we are concerned mainly with the art of radio-telegraphy and radio-telephony, the author may perhaps be forgiven if he selects international regulations as the starting-point of his discussion, since progress in this direction enforces, by mutual agreement between the nations, improvement both in the art and in the practice of radio communication; and, seeing that a new international agreement has recently been reached at Cairo, the occasion to discuss the effects of the 1938 Convention is opportune.

(2) INTERNATIONAL REGULATIONS

The recent plenary International Conference to review the Telecommunications Convention and General Regulations made at Madrid in 1932 was held at Cairo in the spring of 1938. The Conference commenced on the 1st February, and was opened by H.M. King Farouk at the Heliopolis Palace Hotel.

The work of the Conference entailed much study of the business aspects of telecommunication, including such matters as telegraph and telephone tariffs, communication procedure, traffic routing, and many other important factors in the art and practice of telecommunication in all its branches—problems with which we are not concerned in this review. It also included, however, a very important item, namely the revision of the Madrid General Radio Communications Regulations in the light of present-day needs resulting from progress made during the past 5 years, such progress having led to increasing congestion in the ether owing to the tremendous expansion of radio services during this period.

Bearing in mind the importance of the situation thus described and, in particular:—

(*a*) the growth of aerial transport, of which radio-communication in all its forms is a most important ancillary service;

---

* A review of progress.

† Marconi's Wireless Telegraph Company, Ltd.

(*b*) the ever-insistent demands of broadcasting, which have gathered added strength from the increasing weight of public opinion and political activity;

(*c*) the further development of the marine services in all branches, but especially in the short-wave trawler telephony and radiogoniometric services;

the actual modifications made at Cairo to the Madrid General Radio Communication Regulations were considerably smaller than expected.

Nevertheless, considerable changes have been made:—

(i) By virtue of the modifications made in the allocation of frequencies to the various services.

(ii) By the tightening-up of the regulations in respect of the frequency tolerances attributable to the various types of transmitter corresponding to the different services they perform.

The first real allocation of frequencies may be said to have been made at Washington in 1927, largely as a result of experience gained during the Great War and subsequent years, and as a tentative effort to distribute the available frequencies amongst the claimants whose services had comparatively recently (at that time) begun, namely radiogoniometry, broadcasting, radiotelephony for small ships, short-wave point-to-point services, and amateur activities.

The frequency allocations thus adopted were largely influenced by the positions in the radio-frequency spectrum already taken up by the said new services.

At Madrid the frequency allocations were slightly modified to meet growing needs, but frequencies still remained allocated in comparatively wide bands to be shared among various classes of services. This was particularly so in the case of the mobile bands whose frequencies were shared by marine and aircraft services, irrespective of the fact that the types of apparatus practicable for these very different vessels vary considerably in size, weight, and consequently in their technical characteristics.

Great advance was therefore made at Cairo in regard to re-allocations, exclusive bands of frequencies being assigned, in particular to aircraft. Moreover, an effort has been made to facilitate further the solution of the problem of the expansion of the aeronautical services by dedicating exclusive and specific bands of frequencies to the various aircraft routes in contemplation.

Thus the practical result of the revision of the Madrid allocations, so far as aeronautical and marine services are concerned, is that the aircraft radio services have been given the exclusive use of one part of the former mobile service bands and the marine services the exclusive use of the remainder. This separation of marine and aeronautical services, together with the adoption at Cairo of definite tolerance regulations for mobile transmitters, should tend to minimize interference between the two service channels.

Concerning the marine services, some of the changes in the regulations were of necessity subject to commercial considerations. A considerable tightening-up of regulations had been forecast before the meeting, but during the past years a world slump has been experienced and, since the cost of new equipment for what would have been the bulk of the world's shipping would ultimately fall on shipping interests all over the world, too drastic changes could not be made, for economic reasons.

Nevertheless, definite tolerance limits for marine transmitters have now been adopted by the Cairo Conference, whereas at Madrid the recommendations inserted in the General Radio Regulations served only as a guide and not as a definite regulation.

The application of a regulation fixing the tolerance of a ship station entitled to transmit on any frequency within the mobile band is not feasible. The difficulty was overcome at Cairo by a special definition of tolerance as applied to marine transmitters, wherein it is laid down as "the limit of variation from the starting frequency during a 10-minute transmission."

Although this may not appear very drastic, it is to be remembered that most of the frequency drift of the normal simple transmitter occurs during the first 10 minutes, and it is thought that the general effect of this definition, coupled with a new regulation stipulating for the equipment of ship installations with a good wavemeter or its equivalent, cannot fail to be advantageous, while at the same time the employment of an economical form of transmitter still remains possible for ship use.

Ships working in the shared bands (fixed and mobile services) must observe the fixed station tolerances, which impose much higher technical requirements on the transmitter. Progress in this direction is still comparatively slow, since high-class apparatus of the order required is only commercially practicable on first-class passenger vessels, where the extent of the telegraph and telephone traffic to and from such ships justifies the considerable capital expenditure involved.

Technical opinion is, perhaps naturally, biased in favour of the abolition of spark (Type B) transmission for all purposes except for distress signalling, but the bulk of the world's shipping, so far as number of vessels is concerned, consists of cargo vessels compulsorily fitted under Safety of Life at Sea Regulations, whose owners demand the right to use their radio transmitters for the rare messages they may wish to send. Such an argument is difficult to resist, and thus a compromise has been found by limiting the transmission of spark to sets below 300 watts input from the alternator terminals and to operation on 375 kc./sec. (800 m.) for radiogoniometry, 425 kc/sec. (706 m.) for traffic, and 500 kc./sec. (600 m.) for calling and distress signalling.

Progress is thus being realized by the gradual supersession of high-power spark transmitters, such as has taken place during 1938 and must be accelerated and completed by the end of 1939, by which time, so far as British shipping is concerned, at least 1 000 high-power spark sets will have disappeared.

Consideration was also given at Cairo to the large number of small ships operating radio-telephone and radiotelegraph equipments in the region below 1 500 kc./sec. (200 m.). An international calling and distress frequency of 1 650 kc./sec. (181·8 m.) was assigned for such services, and administrations have undertaken to organize a watch to be kept on this frequency at suitable coast stations. This should enhance the "little ship" services and foster further development.

But for a small number of narrow bands relinquished to broadcasting, no marked change was made in the frequency allocations for the fixed services. Although the growth of these services has continued in recent years, yet technical progress in improved methods of frequency stabilization, combined with careful organization of individual allocations, has fortunately rendered the provision of more room unnecessary. The only important change made was the adoption of much more stringent frequency-tolerance regulations for fixed stations.

In the search for new channels, free from congestion and parasitic interference, use is now being made of the waves below 10 m., amongst which the broadcasting of television and the inauguration of inter-island telephony circuits by the British Post Office on waves ranging from 2 to 7 m. or thereabouts are notable examples.

A further sign of progress indicated by the new allocation of frequencies at Cairo is the assignment of all frequencies up to 200 Mc./sec. (1·5 m.) to broadcasting, television, radio balloon sounding, fixed, aeronautical, marine, and amateur services, whereas the Madrid allocations were limited to frequencies up to 60 Mc./sec. (5 m.).

(3) MARINE SERVICES

As has been mentioned, the development of improved ship installations is very closely bound up with the activity of shipping. In consequence, there has been a slowing-up in the application of new designs and improved marine equipments, with the notable exception of expansion in short-wave fittings for world-wide communications and the development of radio-telephone equipment for trawlers and coasting steamers.

Improved Stability

One of the principal difficulties in short-wave working under ship conditions has been the problem of accurate tuning of the transmitter to the degree of precision required by international regulations and also to ensure that the signal is quickly picked up by the coast station without causing interference with other services. By making use of the fact that the marine short-wave bands are arranged in harmonic relationship, it has proved possible to develop a simple monitoring scheme which permits of immediate and direct checking of the tune of the transmitter by reference to a single primary quartz-crystal standard of 345 kc./sec. This relatively low-frequency crystal is of the low-temperature-coefficient type and affords a very satisfactory answer to the question.

Coast Stations

The considerable increase in the number of ships equipped with short-wave radio-telegraph equipment has necessitated corresponding increases in coast-station facilities, and as a result the world-wide short-wave telegraph service operated with ships from the stations at Portishead and Burnham has grown steadily, together with the installation of further transmitting and receiving equipments. The latest transmitters installed are capable of emitting twice the carrier power of the earlier equipments, can each transmit two messages simultaneously, and are capable of very rapid wave-changes such as are necessary in dealing with traffic from ships located in all parts of the globe. The latest transmitter is crystal-controlled by means of quartz crystals of almost zero temperature-coefficient operating at the fundamental radio frequencies assigned to the transmitter, thereby enabling the usual harmonic-generating stages to be dispensed with. Further economy in space is effected by employing pentode power valves in the preliminary amplifying stages.

A simple "quick search" type of short-wave receiver has been developed to speed up the clearance of traffic on this service, the broad principle of the receiver being to convert the incoming frequencies by wide-band demodulators into frequencies lying in the medium-wave broadcasting band and then to employ a more or less conventional type of broadcasting receiver.

Work has been going on steadily with the modernization of the shorter-range coast-station equipments to enable these to comply with the latest permissible frequency tolerances. Some stations have recently been equipped with transmitters having all frequencies stabilized by quartz crystals and designed for operation on both telegraphy and telephony.

Telephony

The increased use of radio-telephony in small vessels such as coasters and trawlers has necessitated much additional organization. Only limited bands are available for this service, into which the ship-to-shore and inter-ship communications of all nations must be packed. The difficulty can be realized when it is understood that there are more than 2 000 vessels of this kind fitted with telephone installations, and nearly all operate in congested and narrow seas. Much has been done through the operation of the North Sea and Baltic Agreements, which allocate frequency bands on a regional basis, thereby reducing the mutual interference. These arrangements are being followed up by the design of new transmitters better able to control their radiated frequencies in accordance with requirements.

Trawlers and Small Ships

Owing to the normal growth of traffic and to the increasing use of radio communication by trawlers and small craft it has been necessary to provide means whereby coast stations may send and receive simultaneously at the same station. This has been done by erecting the receiving aerials about 1 mile from the transmitting station; by connecting these receiving aerials to the receivers by means of low-loss coaxial cables; and by providing selective receivers in a screened room. As a result of these precautions interference from the local transmitters, even where these are of high power, has been reduced to a negligible value. This system, which has been installed at the Wick station, has proved to be entirely satisfactory, and arrangements have been put in hand for similar systems to be installed at other coast stations. Arrangements have also been made for the direction-finding aerials to be remotely situated from the receiving stations at the Lands End and Wick stations, because by this means the arc over which reliable bearings are obtainable can be considerably increased.

A continuous distress watch for trawlers on 181·8 m. has been instituted at all coast stations, and a device has been developed which causes the receiver to search continuously over a band of about 30 kc./sec. every half-minute to cater for ships which may accidentally be transmitting off their nominal frequency.

Express Steamer Equipment

The addition of the " Queen Mary " to the mercantile marine has been a milestone from the wireless engineer's point of view, in that a most complete and effective installation has been fitted. The " Queen Mary " equipment is designed to meet the special requirements of vessels of her class, and will serve as a model for installations of this type. It has recently been very fully described in the paper by Commander Loring and Messrs. McPherson and McAllister.* The installation design was reached after a most careful and scientific survey of the needs of an express steamer such as the " Queen Mary." The manner in which these needs have been met with present-day technical knowledge, having due regard to the special conditions on board ship, is detailed in the paper.

The equipment consists of: (1) Short-wave telegraph and telephone transmitter. (2) Medium-wave telegraph transmitter. (3) Long-wave telegraph transmitter. (4) Four operating positions, with receivers for providing adequate facilities for reception on all wave-bands. (It is possible to key any transmitter on any selected spot wave from each position.) (5) Telephone terminal and privacy equipment. (6) Position for automatic high-speed telegraphy reception and transmission. (7) Emergency transmitter. (8) Auto-alarm. (9) Direction-finder. (10) Broadcast receiver.

As the transmitting room is some 400 ft. distant from the receiving and operating room, remote control of the transmitters is provided. The operators are by this means able to select any of the spot waves required, by a simple dialling operation in the receiving cabin.

Interference with Radio Working on Board Ship

With the increasing use of music reproduction and short-wave reception on board ship, the suppression of " ship noises " (or, in other words, electrical interference with radio working) has become a problem of major importance. Such interference is caused by electromagnetic induction between ships' cables and wiring, usually as a result of the minute sparks which occur at the brushes of all rotating electrical machinery or at the contacts of switches and circuit-breakers of all kinds. The problem has been given careful consideration by the various specialized committees concerned with the revision of the I.E.E. Regulations for the Electrical Equipment of Ships.

(4) DIRECTION-FINDING SERVICES

The rapid growth of both military and civil aviation has greatly stimulated progress in direction-finding. Wireless navigation is carried out by observation of the mobile transmitter from a ground direction-finding station, by the observation of a fixed beacon station from a direction-finder installed in the moving vessel, or by the use of some type of equi-signal or " beam " type of ground transmitter to lay down a course for the aircraft or ship. The fact that aircraft need bearings at long ranges both by day and by night and may require the observations to be made in the short-wave band has led to a close study of methods of direction-finding which are free from the errors encountered under these conditions when using the conventional rotating loop or radio-goniometer.

Adcock Direction-finders

Development has continuously taken place as regards the solution of technical difficulties in the application of the Adcock principle. This basic idea depends for its success upon a recognition of the fact that all random direction-finding errors of practical importance are due to reception by portions of the aerial system lying in a horizontal plane. Two main methods of countering the effects are employed. We may either arrange the horizontal members of the receiving aerial so that they are symmetrically disposed in such a way that the voltages induced by the incident electromagnetic waves are always equal and opposite, so that their effects cancel, or we may electrically screen all horizontal conductors from the effects of the arriving radiation. From the engineering standpoint each way has its merits. In effectiveness in removing the errors there is little to choose between them.

The polarization-error-free direction-finder has now been established on a firm foundation; many such equipments have been erected both at home and throughout the Empire, and are playing an important part in aerial navigation.

Mobile Installations

Improvements in mobile direction-finding equipment for ships and aircraft have been mainly in the direction of neater and more convenient designs suitable for use by the navigating officer, supplemented by the study and incorporation of various methods of obtaining visual indication of the bearing of a selected beacon station. The latest types of direction-finder are tuned by means of a single knob, and the beacon stations employed by a ship on any particular run are as easily picked up and identified as the stations on the familiar home broadcast receiver. Visual indication of the bearing of the beacon station, in general, takes the form of some pointer instrument or cathode-ray tube which tells the observer when he has oriented his pointer correctly to read off the bearing required. Several types of direct-reading visual indicator in which the bearing itself may be directly read on a scale are under development, and some equipments of this type have emerged from the laboratory and are undergoing practical trials.

Cathode-ray Methods

In this connection mention must be made of the " comparator " method of using a cathode-ray oscillograph as a direct-reading visual direction-finder. The result is achieved by employing two frame or Adcock aerials in mutually perpendicular planes, each being separately tuned and the received currents being separately amplified before application as independent voltages to the deflecting pairs of plates of the oscillograph. By careful attention to the removal of amplitude and phase distortion in the two chains of receiving circuits it is possible to make the trace on the screen of the tube indicate the bearing of the station under observation, the combination of the effects from the two frames being exactly analogous to that in the familiar Bellini–Tosi radiogoniometer, but having the advantage of giving an instantaneous visual indication which is continuously observable. This method has been very closely studied and is finding considerable application in cases where rapidity and directness of observation outweigh such considerations as cost, simplicity, and wave-range.

---

* *Journal I.E.E.*, 1937, vol. 81, p. 183.

Equi-signal Beacons

The equi-signal beacon continues to be the subject of study and development both at home and abroad. It finds its main applications in air-route guidance and in aerodrome approach and landing aids, about which more will be said later in this review.

Maritime Radio Beacons

The period under review has seen a steady growth in the number of beacon stations available for marine navigation. This activity has been accompanied by improvements in the performance of the stations, especially in regard to (i) frequency stability and (ii) methods of modulation. These points are now of special importance inasmuch as the increase in the number of beacons is rendering the packing of the stations into the small frequency band available increasingly difficult. A further factor in the move towards accurate carrier-frequency stabilization is the greater personal use by navigating officers of the marine direction-finder. Under these circumstances it is essential that the carrier frequency of any beacon should be accurately controlled in order that it may tune exactly at the point on the tuning scale of the direction-finding receiver at which it is expected to appear. Variation in this respect might lead either to wrong identification of a beacon or to failure to receive it.

The utility of the beacon services has also been enhanced by the provision of two additional facilities for direction-finding calibration. For this purpose a programme of transmissions has been arranged to take place daily, the beacons sending at specified times for 1 hour in the morning and 1 hour in the afternoon, each programme consisting of 10 successive fog transmissions. In addition to this an " on request " service has been commenced, whereby any beacon will transmit the fog programme continuously on request by a ship requiring calibration. After notification of the authority concerned, the ship, on arrival off the beacon, gives a visual and sound signal (black ball at mast head and blast sequence on ship's whistle); the beacon will then commence to transmit and will continue to do so until the ship notifies the beacon that the calibration is complete.

Beacon Equipments

A number of Trinity House beacons have been brought up to date by the use of high-precision master oscillators whose stability is of the order of 1 in 25 000 or better, all new installations being now equipped with quartz oscillators in order to comply with the Cairo requirements. Similarly on British lightships the process of replacing existing telephone sets to meet the new regulations is proceeding. Such sets now have a tolerance of 1 in 10 000.

The original remote-controlled fog gun in the Clyde is also being modernized by the use of a crystal-controlled transmitter, which now permits the use of a receiver so selective that false alarms are practically a thing of the past.

The Northern Lighthouse Board has also been active in increasing the utility of the service, and beacons have been put into service at Barra Head and Port St. Mary (Isle of Man). A further station is in course of erection at the North Uist Lighthouse. The Barra Head station is of interest in that the aerial crosses a gully and is, in consequence, about 700 ft. above sea-level. This station has proved to have a range of over 200 miles.

The same authority has also been actively proceeding with the equipment of lighthouses with radio-telephone equipment to maintain communication with the shore.

(5) AERONAUTICAL COMMUNICATIONS

There has been a steady expansion in the normal aircraft-to-ground communication facilities, in keeping with the growth of the commercial services. It should, however, be remembered that the development of this type of facility must always take second place to meteorological services and navigational and landing aids. In any case the demand for telephonic or telegraphic contact between passengers and ground is small, since the present continental journeys are of short duration. With the development of long-distance flying this situation may change.

Aircraft Direction-Finding

Much progress has been made in direction-finding both from the ground and in the air, and this section of the work is dealt with under " Direction-finding." A directional aid which is wholly specialized in the aircraft field is the system of aerodrome approach and landing guidance in bad visibility, which has been the subject of parallel development in various countries.

Briefly, the principle of the system is to provide, from an ultra-short-wave beacon at a selected spot on the aerodrome, a radiated space pattern at an angle from the ground in the vertical plane, such that a pilot can be guided accurately along a sharply defined path of interlocking signals to the aerodrome, and thereafter, by watching the movements of a second needle indicator, receive some check on his angle and rate of descent to the landing runway. The position of the aircraft relative to the aerodrome is defined by means of marker beacons generally located along the approach path, one at the edge of the landing ground and another a few miles away, their duty being to indicate, by means of ultra-short-wave beams directed vertically, known points at which the pilot should adjust his height preparatory to the descent. Although many satisfactory demonstrations have been given of the utility of the system, it requires more investigation before the landing problem can be regarded as completely solved. Much active work is in progress with a view to improving the reliability of the method, to simplify the equipment in the aircraft, and to make the indications as positive and unambiguous as possible. This work covers the development of interlocking-pattern beacons and the study of observed day-to-day variations in the position of the glide path.

Intercontinental Flying

The recent flying-boat flights across the Atlantic in both directions have been of a much more routine character, and undoubtedly presage the establishment on a commercial footing of intercontinental services involving difficult transits. This work has led to the development of much more ambitious aircraft equipment operating in the short-wave bands for long-distance communication. An example of such an aircraft transmitter is that installed in the Imperial Airways flying boats " Caledonia " and " Cambria." This transmitter covers a waveband of from 15 to 1 100 m. in six ranges, and delivers 60–75 watts to the aerial. Instantaneous operation on one of six pre-selected waves is provided, and the whole transmitter occupies less than $2\frac{1}{2}$ cu. ft., and weighs just over 50 lb. These developments have resulted in corresponding changes in receiver designs to cover much wider wavebands and to give the best possible performance for short-wave long-distance communication. Increasing use is being made of both mechanical and electrical systems of remote control for aircraft apparatus. In planning a commercial aircraft equipment it is advantageous to be able to place the instrument itself (transmitter, receiver, or direction-finder) in the most suitable position from the point of view of the layout of the accommodation, and to lead the controls to the pilot's or navigator's position via easily-fitted flexible connections. In consequence, there have recently been developed various aircraft sets embodying this principle and using either mechanical or electrical means of obtaining the control over the connecting links.

(6) LONG-DISTANCE TELEGRAPH CIRCUITS

Progress in telegraph circuits has been mainly confined to the study of traffic requirements and the development of engineering and organization methods hand-in-hand, to give the best service between various points in the world which economic considerations indicate.

Minimum-delay Circuits

A very good example of a development of this kind is afforded by the so-called " Shorter's Court " telegraph circuit linking the London and New York Stock Exchanges. In this case the object is to secure the interchange of information with the absolute minimum of delay which can be achieved. For the purpose of this circuit special telegraph offices have been established adjacent to the New York and London stock exchanges. In London, the office is in Shorter's Court, and is directly accessible to the Stock Exchange itself. Members hand their messages to the transmitting clerk, and arrangements are such that a circuit is always available for instant use.

For the service it has been found necessary to reserve five separate in and out circuits between London and New York. These wireless circuits are kept permanently established across the Atlantic and as many channels as desired are capable of being operated simultaneously electrically in parallel, as circumstances require. This parallel operation is adopted to secure the maximum freedom from questions (RQ's) and replies (BQ's) relating to transmission and reception faults. The engineering precautions taken to avoid interruption of the service are very complete, and include such factors as completely independent power supplies for the circuits, and different wavelengths for the radio links, while separate landlines connect each individual radio transmitter and receiver to the Stock Exchange Office.

Various points affecting the normal design of terminal apparatus have received attention. For example, a special tape transmitter is employed which operates with a delay of only 10 centre holes between the sending point and the keyboard perforator. This development avoids the delay in the storage loop which normally exists between the perforator and the transmitter. Also, at the receiving position the actual tip of the writing siphon is directly visible, at a readable position, to the receiving typist, and so no delay in transcription occurs.

For timing, special time stamps which endorse the messages with times of handing-in and of reception to an accuracy of ± 6 sec. are employed.

Since the offices are not actually in the Exchanges, but adjacent, messages have to be carried by hand to and fro. To speed up this work the messenger boys are fitted with running shoes, and in and out traffic is separated by a white line on the connecting staircase and passage to avoid delay due to collisions.

As a result of all these developments it has proved possible for a member of the London Stock Exchange to hand in his message for a member of the New York Stock Exchange and to be handed a reply in 24 sec. The average delay is less than 60 sec.

Printing Telegraphy

The consolidation of the cable and wireless circuits has led to the adaptation of the printing telegraph methods employed in cable telegraphy to radio purposes. In general, only high-grade radio circuits are suitable for these applications. In order to make the best use of the wireless circuit, double channelling in time sequence is employed by making the synchronized selecting apparatus of the cable printer also perform synchronized channel switching. In this way two independent channels are established, which under good radio conditions are operated independently. When conditions deteriorate to the point where the number of errors is too great the channels send the same message simultaneously but with a time interval of 2 sec. between the transmissions. This delay is obtained, not by actual retransmission from the tape but by the storage of the signals passed from the tape transmitter in a condenser storage device. These stored signals are subsequently released into the second channel with the required time delay. At the receiver the first-channel signals are stored in a similar condenser storage device; on arrival of the second-channel signals the two are automatically compared, and if the required correspondence is found the type printer is set up and operates. In its present stage of development the apparatus can be adjusted to give best readability, either through fading or, alternatively, through atmospherics and noise. Experiments are in progress whereby it is hoped to deal with both conditions simultaneously.

A radio circuit has been set up between London and Ascension which forms part of long cable chains extending to Buenos Aires and Cape Town, the connection being maintained without manual transfer at any point. The establishment of this circuit has necessitated the development of a relaying system which converts the 3-element cable code to the normal 2-element (on/off) used in wireless telegraphy. This has been successfully carried out and the circuit is now part of normal world communications.

Reduction of Fading

Frequency wobbling of short-wave transmission to reduce fading has been further developed. This method has advantages over amplitude modulation in that: (*a*) The power of the transmitter is not reduced. (It is necessary to reduce the power of a given telegraph transmitter when amplitude modulation is applied, since the usual limitations governing telephony transmission apply.) (*b*) The spectrum of the radiated wave shows that the energy is more concentrated in the bands adjacent to the carrier, and consequently less sideband interference is produced.

For the purpose in view it has been found that a suitable modulation is provided with minimum sideband spread if the frequency of the shift is at 400 cycles per sec. with a carrier frequency swing of ± 800 cycles per sec. This method of reducing fading is in use on most of the short-wave telegraph transmitters where spaced-aerial (diversity) reception is not employed at the distant terminal.

One of the cheapest ways of effecting an improvement is by the use of the series phase directive receiving aerial, the design of which has been the subject of study. This type of aerial is now largely used for the reception of telegraph signals. In this connection it is interesting to note that an increase in directivity of the aerial system may result in a reduction in effectiveness of a circuit due to an apparent increase of fading. In explanation it is suggested that these waves undergo large angular deviations at times.

Miscellaneous

The approach of the next sunspot maximum has necessitated the provision of additional plant and aerials to meet the anticipated adverse conditions. These preparations even envisage the possibility of increased use of long-wave circuits to maintain communications.

A permanent record of earth-current intensity is now kept. It has been found that these currents increase about 2 hours before a general fade occurs. This discovery is of importance in that traffic diversions may be arranged to forestall the fade and so minimize the attendent dislocation of the services.

A system has been developed whereby two independent telegraph signals may be emitted from a single transmitter and applied to a number of short-wave telegraph transmitters both on point-to-point services at Leafield and on the long-distance ship service at Portishead. Briefly, this system consists of providing two crystal oscillators in each wave-range, which produce two carrier frequencies some 6 or 8 kc./sec. apart. These two frequencies, by means of a third oscillator, are radiated alternately, under "marking" conditions for periods of approximately 0·0025 sec., and two messages can be sent by individually "keying" the two carrier frequencies. The system has helped materially to reduce delays in handling traffic during busy hours without appreciable addition of transmitting equipment.

(7) LONG-DISTANCE TELEPHONE CIRCUITS

Further radio-telephone services, all using short wavelengths, have been opened to Japan, Kenya, Iceland, and Kuala Lumpur (via Bandoeng); and a temporary service has been opened to Portugal since that country has been isolated telephonically from the rest of Europe during the present trouble in Spain.

Short-wave Telephone Reception

As has already been mentioned, there has been some evidence, during the early part of 1938, indicated by adverse transmission conditions, of the approach of high sunspot activity and magnetic variations; these are expected to reach a maximum during 1939–40. Attention has naturally been turned to methods whereby the resulting dislocation of telephone traffic under disturbed conditions of short-wave propagation may be reduced. A new technique of reception has been developed which, it is hoped, will offset to some extent the bad conditions to be expected, and the British Post Office is co-operating with the Bell Telephone Laboratories in America in this work. One of the most impressive features of the new method lies in the aerial system, which consists of 16 rhombic aerials in line, covering about 2 miles in the direction of reception. Each aerial is connected individually to the receiving station by an underground coaxial copper-tube line. By adjustment of the relative phases of the high-frequency currents induced in each antenna it is possible to produce a sharply defined cone of reception, the axis of which can be directed in both the horizontal and vertical planes. By this means the circuit degradation due to interference between rays arriving by different paths, as evidenced by both fading and speech distortion, can be reduced.

One telephone channel to America, working on short wavelengths, has been operated on traffic on the single-sideband reduced-carrier system for some time, and has given satisfactory performance. The expected improvement in signal-to-noise ratio has been generally obtained, but changes in the levels of the output from the receiver under conditions of deep fading were found to be accentuated compared with the normal double-sideband system. To overcome this a " constant volume " amplifier has been added to supplement the automatic gain control of the receiver. The constant-volume amplifier is connected between the receiver output and line and, over a wide range of input levels, supplies a level to line which is constant within ± 2 db.

Miscellaneous

Experiments whereby two separate conversations may be transmitted by using two separate single sidebands, one on either side of the nominal carrier frequency, have been in progress for some time and give promise of being very successful. The possibility of doubling the number of available channels by this method of working has obvious advantages in view of the congestion of the short-wave frequency spectrum, and also allows the introduction of improved secrecy systems.

Improvements to the equipment at the radio-telephony terminal have been made in an endeavour to improve the service to the subscriber. The expander portion of a " compandor " has been modified to act as a " noise reducer " by a slight alteration of its characteristic, whereby incoming signals below a certain arbitrary adjustable level, i.e. chiefly noise, are attenuated, and signals above the arbitrary level—chiefly speech signals—are passed without loss. This apparatus has been used very successfully on some difficult circuits, but it must be used judiciously since it further accentuates fading. On circuits where fading is not too severe an increase in the commercial grade of circuit is generally obtained.

To improve the control of the level passed to the transmitter, which is usually carried out manually, an " automatic technical operator " has been developed and tested successfully. This device performs the function of passing a constant level of signal to the transmitter irrespective of the variations, within wide limits, of the incoming level from the subscriber.

(8) ULTRA-SHORT-WAVE CIRCUITS

Increasing use has been made of frequencies above 50 Mc./sec. to provide communication between points separated by water where the distance does not exceed about 100 miles; and several islands round the coast have now been provided with telegraph and telephone circuits by radio equipments using these frequencies. Transmitters, of power output varying between 1 watt and 250 watts, depending on the range required, have been developed for working on these frequencies with the carrier frequency controlled by quartz, or in some cases tourmaline, crystals. Superheterodyne receivers, having the first beating oscillator frequency controlled by a suitable quartz crystal, have also been developed simultaneously for the services. In cases where more than one circuit is required, apparatus has been developed whereby two speech channels may be simultaneously impressed upon a common radio-frequency carrier, and such a system has been in successful operation for over 2 years to provide telephone circuits between the mainland and the Channel Islands. In parallel with these developments a 9-channel multiplex ultra-short-wave equipment has been installed for working between Scotland and Ireland across the North Channel, and in this equipment all nine speech channels are imposed upon one radio-frequency carrier.

Telegraph circuits using a voice-frequency teleprinter working over ultra-short-wave radio links have been provided to the Scilly Islands, and will shortly be provided to several islands off the coast of Scotland.

(9) MILITARY EQUIPMENT

Progress in military equipment has lain principally in the application of better methods and materials which have become available with the advance of the art. Examples of better methods are the use of voice-switching in telephone apparatus and automatic listening-through devices for telegraphy. Materials such as iron-dust cores and ceramics with special properties have enabled the size and weight of the sets to be reduced and the robustness and reliability to be increased. It is interesting to consider three main types of equipment, namely medium-power pack sets, small-power man-pack sets using batteries, and tank sets.

Medium-power Pack Sets

The power supply for these sets is either a pedal-driven or a light-engine-driven generator. A very simple form of voice-operated carrier suppression for telephony is now incorporated and the same device is used for listening-through on telegraphy. By "listening-through" is meant the ability to hear the distant station in the intervals between the elements of the morse characters being sent by the local transmitter. Inter-tuning is also provided, which enables the receiver to be set to exactly the transmitter frequency and vice-versa. The transmitter circuits are completely ganged, so that any desired wave may be selected by a single adjustment. A separate rod aerial is also employed for the receiver, to permit of continuous watch-keeping when on the move. Pentode valves are used in the transmitter circuits to eliminate neutralizing arrangements with their added weight and complexity. The wave range covered by these sets is generally about 30 to 750 m. The range is usually about 100 miles for telegraphy and 30 miles for telephony.

The receivers are of the superheterodyne type with simplified adjustments. They incorporate all such modern ideas as iron-dust cores, automatic volume control, illuminated scales (which are also provided for the transmitter), drum switching of coils for various ranges, etc.

Small-power Man-pack Sets

Batteries are used as the source of power. The wavelengths are in the region of 100 m. A typical complete pack—transmitter and receiver, aerial, and all supplies—is under 30 lb. in weight. The aerial is an integral part of the set, and the whole equipment can be operated whilst on the march. The transmitter and receiver are tuned simultaneously by one handle, thereby speeding up the process of establishing communication. The sets are arranged to work on either C.W. or telephony, and the aerial power is of the order of 1 watt. These outfits will give a range of about 7 miles on telephony and 15 miles on C.W. telegraphy.

Another still lighter type of equipment for restricted ranges is one operating in the ultra-short-wave band, generally in the region of 5 m. The complete pack weighs about 12 lb. and works on telephony only. Its range is about 2 miles over flat land, but contact has been made up to 20 miles between hills or other elevated positions.

Tank Sets

These sets are arranged to operate from a 12-volt battery which is interchangeable with the tank motor-starter battery. The wavelength employed is about 100 m., and ranges up to 10 to 12 miles are obtained on telephony between aerials permanently fixed on the tanks.

The receivers are provided with visual indicators to facilitate the process of establishing common-wave working on the frequency chosen by the commander tank. Superheterodyne reception is employed and one-knob control is provided, the scales being directly calibrated; very good frequency discrimination is obtained. The complete transmitting and receiving circuits are contained in a box only 15 in. × 11 in. × 7 in., fitted with special shock-absorber mountings.

For small tanks and armoured cars a set somewhat similar to the battery-driven man-pack equipment is employed. These sets are made easily detachable from their mountings so that they may be employed in the field if required.

It is important to note that all military telephone equipments may be used with a special microphone which is strapped to the neck of the operator. This enables him to continue working whilst wearing a gas mask.

(10) RESEARCH AND DEVELOPMENT

Ionospheric Investigations

Considerable additions to our accurate knowledge of the ionosphere have arisen from the development of manual and automatic recording by means of pulses, of the variation of the ionospheric heights with the frequency of the emitted wave. The results yield the heights and maximum ionic densities of the layers concerned, i.e. the E layer at about 100 km., the F_1 layer at 220 km., and the F_2 layer at 250 to 400 km.

Material obtained in various parts of the world has made known the diurnal, seasonal, and year-to-year change in the ionospheric characteristics, as well as latitude changes in some isolated cases. Although the information is by no means complete enough for a world survey, it has been sufficient, with the help of eclipse results, to confirm that the E and F_1 ionization is produced in a fairly regular manner by the sun's ultra-violet light.

The mechanism of the ionization of the F_2 layer is not yet understood. It has been found that the maximum ionization in the layers varies largely throughout the sunspot cycle, being greatest when the sunspot numbers are greatest. This causes the now well-known cyclic change in the optimum waves for long-distance transmission.

The theory of the double refraction of vertically-transmitted wireless waves in the ionosphere has been developed and checked experimentally. It has been found to explain accurately the splitting and polarization observed on downcoming waves. In particular, it has been confirmed that free electrons, and not positive ions, play the predominant part in refracting electric waves in the ionosphere. A great deal of information has also been obtained in the propagation of long waves, both as regards their height of reflection and their downcoming polarization.

Although the theory of oblique (glancing incidence) transmission has not been advanced to such an extent, progress has been made by the formulation of a very important equivalence theorem, according to which the oblique-incidence characteristics can be derived from the vertical-incidence characteristics. The theorem is known to be not quite accurate, but experimental tests made so far agree closely with the theoretical results, so that the inaccuracy cannot be very great. It is now possible to obtain with very fair precision, from the vertical-incidence measurements, the skip frequency for any given distance.

Constitution of the Ionosphere

Recent measurements at vertical incidence of the reflection coefficient of the ionosphere have shown how it is possible to measure the electron collision frequency and hence the specific attenuation, at various points in the layer. It has been confirmed that practically all the loss in long-distance transmissions occurs in passing and re-passing through the E layer, with a resultant attenuation inversely proportional to the square of the frequency. On the purely physical side these collision-frequency results, coupled with the diurnal density variations, have suggested that the upper atmosphere (above 200 km.) is at a very high temperature, estimated to be 1 000° C. The seasonal and diurnal variations of this temperature are not known with any certainty.

High-power impulse technique has revealed the presence of irregular but fleeting ionic clouds in the E region of the ionosphere. They are present both by day and by night, produce scattered signals, and set a limit to the accuracy of direction-finding at distances where the ray reflected from the ionosphere is important. In this connection it may be mentioned that the long and difficult problem of producing a direction-finder entirely free from polarization error has been solved. The spaced-frame system, although not yet in a practical form, has reduced these errors to less than the residual errors caused by lateral deviations of the rays in the ionosphere.

Magnetic Storms and Sudden Fades

This review would not be complete without a reference to the investigation of magnetic storms and sudden fades which cause such disastrous interruptions to various services. The poor conditions in high magnetic latitudes, associated with magnetic storms, have long been known. It has now been found that the effects are associated, in general, with a reduction of ionic density in the F_2 layer, and an increase of attenuation in the E layer. The completely different character of another type of sudden violent fade, starting very abruptly and lasting generally for minutes rather than hours, has now been recognized. These fades occur only when the transmission path is wholly daylight. Convincing evidence has been obtained to show that these fades, which are often accompanied by an increase of noise, are associated with bright hydrogen eruptions from the sun, which presumably produce violent ultra-violent emission which penetrates below the E layer, producing excessive attenuation. These fades have become much more numerous with increasing sunspot activity.

Transmission Theory

The theory of transmission over a flat, imperfectly conducting, earth has been refined, and some of the original difficulties and obscurities have been cleared up. In particular, the theory of ultra-short-wave ground-ray propagation has been extended to keep pace with television developments. The complete theory of the diffraction of waves round a spherical earth of any conductivity has been treated by three methods which are all in substantial agreement.

These theories include the effect of raising the transmitter and receiver above the ground, and one of them allows the effect of refraction to be estimated. Measurements have shown that the signal intensity at places beyond the visual range is greatly in excess of the calculated values, and this implies that there is considerable refraction in the lower atmosphere.

In this connection, measurements with very short impulses have shown that weak reflections corresponding to equivalent heights of 5 to 60 km. sometimes occur. Their origin is as yet unknown. They may be responsible for some of the effects observed in ultra-short-wave transmission beyond the visual range.

Frequency Control

One of the most remarkable developments of recent years has been the universal improvement in frequency stability of continuous-wave transmitters of all types, varying from the very high-power broadcasting station to the small mobile or portable equipments of a few watts output. This improvement has been fostered by the Regulations resulting from the C.C.I.R. Recommendations relating to frequency stabilities and tolerances established at the various international conferences. These Recommendations and Regulations have stimulated work on methods of frequency control, resulting in the accommodation of more and more services in the allotted bands. This closer packing of the channels has again added impetus to this branch of research, on account of the prime necessity for avoiding mutual interference.

The methods of control now employed vary with the type of service, and the transmitters fall broadly into two classes: (i) Those required to transmit one or more fixed spot frequencies. (ii) Those required to cover a wave band and to be able to transmit any selected frequency within the band.

The requirements of the spot-frequency transmitter have proved to be best met by some form of electromechanical primary oscillator. In the early days various forms of valve-maintained tuning forks, steel-rod oscillators, etc., combined with suitable frequency multipliers, were employed. During the last few years, however, the simplicity and directness of the piezoelectric quartz resonator (which can be designed to have a fundamental frequency as high as, for example, 20×10^6 cycles per sec. and to oscillate reliably at this high frequency when maintained by a suitable valve circuit) have won the field for this type of frequency control.

Studies have been made of the high-frequency properties of sections cut at various orientations to the natural axes of the virgin crystal. These investigations have resulted in the establishment of definite rules in regard to the cutting of sections having a substantially zero coefficient of change of frequency with change of temperature. It has been found that various angles of cut and shape of section have special advantages in different regions of the radio-frequency spectrum.

Other investigations have revealed the methods of section whereby crystals having a single major response frequency can be produced. One of the troubles has been the presence of various modes of oscillation in quartz plates. The resonator will oscillate in such alternative modes as will produce the required piezoelectric reactions. It is now possible to choose the section in such a fashion as will accentuate the desired oscillation and so make it certain that the correct frequency of oscillation is always obtained.

All the foregoing work has rendered it necessary to have means of determining with accuracy the principal axes of the natural quartz. By examination of prepared lumps of the original crystal under polarized light, together with the inspection of an etched surface microscopically, the positions of the axes can be determined very accurately. By these means it is now possible to cut slices at predetermined angles in the sure knowledge that they will display the desired characteristics when finished.

Study has also been made of the phenomenon of electric " twinning " in quartz. It has been found that this defect is clearly revealed on a visual inspection of an etched surface at right angles to the optic axis of the crystal, when the two angles of crystallization, together with their random boundary surface, are clearly visible.

By the careful application of this work, combined with a study of mountings in relation to the nodal points of the section when vibrating, it has been found possible to produce a stability of frequency of oscillation of the order of 1 in 10^8. It is interesting to note that this stability may be compared with an accuracy of timekeeping of a clock to within $\frac{1}{3}$ sec. per year.

Of course, this high stability is not required in normal transmitter-frequency control, where a steadiness of a few parts in a million is all that is required. For this purpose the quartz sections are mounted in very simple holders which will plug into suitable sockets, and the cost is remarkably low. The low cost renders their use possible in all spot-wave transmitters of normal type.

For transmitters of other types the adjustable inductance-capacitance oscillatory circuit is still used. Much work has been done, however, in the experimental study of various types of temperature-compensated inductance coils and condensers. The suggestions and experiments which have been made are legion. Suffice it to say that although stability equal to that given by the quartz oscillator under varying temperature conditions has not been achieved, nevertheless the inductance-capacitance oscillator has reached a stage where its performance is satisfactory in many cases where a continuously adjustable frequency is required in some specified band.

The aim of all the foregoing work is principally to remove the necessity for thermostatic control of the primary oscillator. This temperature control has been a major difficulty in the design of frequency-stabilizing apparatus for small and mobile stations. The removal of the necessity for its use is no mean achievement.

Adcock Direction-finder

The increasing use of the Adcock direction-finder has revealed errors which experience with the normal rotating frame direction-finder would not lead one to expect. Study has shown these errors to be due to lack of uniformity in the electrical properties of the soil in different parts of the site of the Adcock aerials. Careful work has shown that a single vertical conductor does not exhibit the same effective height for waves incident in different directions. Also, of course, the four aerials, although accurately and identically symmetrical physically, may have electrically different heights. In general these effects are not large enough to be of major importance; but on very difficult sites they may have a controlling influence on the usefulness of the station. Methods of correction are at present the subject of study.

The design of radiogoniometers for use in all types of fixed-aerial direction-finders has been much improved. This improvement has been principally due to the development of better methods of measurement and measuring apparatus, especially in the very high-frequency regions.

The progress of direction-finding has led to the development of multi-channel direction-finders which operate *via* long buried cables connecting the aerial system with the radiogoniometers and receivers. These multi-channel equipments will now work with complete absence of interference between channels and with an accuracy of better than ± 1° on all channels.

Signal-measurement Apparatus

Improvements in ultra-high-frequency signal-measuring apparatus are also to be recorded. Apparatus has now been developed working from 15 m. down to 2 m. The apparatus is simple to use and is self-checking. A part of this work has involved the investigation of the behaviour of thermocouples with currents of very high frequency. Errors of as much as 50 % have been observed, and new designs of apparatus for current measurement have resulted.

Work on signal-measurement apparatus in the band from 14 m. to 2 000 m. has been directed towards the simplification and improvement of practical engineering measuring instruments. Direct-reading signal-measuring equipments in this band now exist which will measure signal strengths from $\frac{1}{4}$ microvolt to 1 volt per metre.

Commercial-service Receivers

Steady progress has been made in the improvement of commercial telegraph and telephone receivers. The improvements consist principally in the careful and scientific application of such components as iron-dust cores (toroidal in shape), crystal band-pass filters, and improved automatic frequency-control (self-tuning) apparatus, to receivers. The stability and reliability which this considerable work has secured is such that it is now possible to switch on a complex short-wave telegraph or telephone commercial receiver at any desired moment with the certainty that the circuit will operate at its best without any preliminary tuning or adjustment whatsoever, and to leave it running unattended for as long as the circuit is open. These improvements have greatly simplified and reduced the cost of running a commercial receiving station.

Vacuum Tubes

The development of television has led to much work on tubes for use in pick-up cameras, and, in parallel, large cathode-ray oscillograph tubes with much improved electrode systems have been produced. This aspect of the subject is dealt with in another review.

Electron Multiplication

An interesting application of the phenomenon of secondary electron emission, long familiar in the "dynatron" valve characteristic, has been found in the development of the "electron multiplier." Broadly, the principle lies in the fact that it is possible to liberate five or more electrons from a target surface by the impact of one high-speed electron. By disposing a collector electrode maintained at a suitable positive potential near to the target the secondary electrons may be made to fall on it. In this case the current arriving at the collector anode may be several times greater than the current in the original electron stream impinging on the target. The process may be repeated a number of times, and so a very large magnification of the original current may be obtained. The method is especially applicable to the magnification of the small currents from photo-electric surfaces. The photo-electrons may themselves be accelerated and form the primary electron stream to be multiplied. In this way Johnson noise in the input circuit of the usual photocell plus thermionic-valve amplifier may be avoided. Electron multiplication has not so far proved an advance on more conventional means for the amplification of the currents in wireless receiving circuits. Probably the fundamental reason for this lies in the fact that most of the noise in a receiving circuit originates in thermal agitation of the electrons in the input circuit.

"Beam" Valves

Another important development has been the "beam" valve. By using an electrode system somewhat similar to that of a cathode-ray oscillograph it is possible to produce a flat ribbon-like beam of electrons which can traverse a space and then fall on a tiny target maintained at a suitable positive potential. The current intensity in the beam can be controlled by the usual control electrode. By adopting this construction, valves having very small electrode capacitances can be made, and, what is more important, the inter-electrode capacitance between anode and control grid is extremely small, being of the order of only 1 per cent of that of the normal screen-grid valve. The valve lends itself to good screening design, and thus very perfect isolation between input and output circuits can be secured.

The use of a similar principle is shown in the design of the "aligned grid" electrode assembly now used in most multi-electrode valves. In this construction the control, screening, and other grids are so made that the constituent wires of successive grids lie directly behind each other in the path of the electrons from cathode to anode. Thus, the wasted currents to the various grids are reduced since successive grid wires lie in the shadow cast by those nearer the cathode. This method of construction is of special importance in valves for transmitters and output power valves for speech amplifiers.

It is impossible in the course of this brief review to deal with the many-sided activities of research in this field; the foregoing examples are selected from the large amount of work going on in vacuum-physics laboratories both at our universities and in commercial undertakings.

High-frequency Cables

The development of multi-channel carrier telephony and the engineering problems arising from the necessity, in some cases, of transmitting and receiving from aerial systems remote from the station buildings, have led to extensive studies followed by the development of various types of high-frequency cable. The considerations are: (1) that the loss in transmission shall not be excessive, and (2) that the constants of the cable shall not be such as to render the design of termination transformers impracticable.

The ideal cable is a copper tube outer with a smaller concentric inner tube supported at intervals by insulators of high resistance and low dielectric loss. The working dielectric is air or other suitable dry gas. Cables, or "feeders," of this type are technically the best but are expensive to make, install, and maintain.

Insulating Materials

As a result of the study of insulating materials it is now possible to construct semi-flexible high-frequency cables. It has been found that certain thermo-plastic polymerized compounds having a styrene base have the necessary dielectric properties, and are flexible. Many designs of cable have been evolved, but in general the insulation is formed as a thread which is wound round the core, and the whole then has a lead sheath extruded over it to form the outer concentric conductor.

Improvements in ceramic insulating materials have also rendered it possible to adopt designs utilizing freely this type of insulation in the form of beads or discs. Some of the new ceramics have a dielectric loss not much greater than that of air.

(11) ACKNOWLEDGMENTS

The author is indebted to Trinity House, the Northern Lighthouse Board, the National Physical Laboratory, International Marine Radio Co., Ltd., Standard Telephones and Cables, Ltd., Marconi's Wireless Telegraph Co., Ltd., and in particular to the General Post Office and Messrs. T. L. Eckersley and G. M. Wright, in preparing this review of the science and art of radio-telegraphy and radio-telephony.

BROADCASTING AND TELEVISION*

By Sir NOEL ASHBRIDGE, B.Sc.(Eng.), Member.†

PART 1. SOUND BROADCASTING

General Development

During the period under review—from the end of 1934 to the end of 1938—the number of licence-holders in European countries for which reliable statistics are available has increased by more than 60 %. During the first 3 years of this period there was an increase of 50 %, the figure for 31st December, 1937, being 31 738 120. Under the Lucerne Plan of 1934 there were 254 broadcasting stations in Europe, the total power being 4 300 kW. The mean power of these stations was about 17 kW and the highest power radiated by any transmitter was 500 kW. At present there are about 280 medium- and long-wave stations in Europe, with a total power of more than 8 100 kW. The maximum power of any station is still 500 kW, but the mean power has increased to about 29 kW.

In this country the number of licence-holders has increased from 6 747 340 at the end of December, 1934, to 8 908 366 at the end of December, 1938. The scheme of broadcast distribution has steadily progressed and it is now estimated that 98 % of the population of Great Britain and Northern Ireland can receive one programme satisfactorily both by day and by night; furthermore, 84 % of the population have a choice of two or more B.B.C. programmes. This result has been achieved by the construction of a number of new transmitters. The long-wave station at Droitwich had already been completed before the end of 1934. It was followed in February, 1935, by a 70-kW medium-wave transmitter on the same site, which covers the Midland Region and replaces the old Regional transmitter at Daventry. In March, 1936, a 100-kW medium-wave transmitter was put into operation at Lisnagarvey to provide a Regional programme service for Northern Ireland and to replace the low-power transmitter at Belfast. In October of the same year a 60-kW transmitter was opened at Burghead to serve the North of Scotland, and in February, 1937, a medium-power station at Penmon began to provide a Welsh programme service to the Northern part of Wales. In July of that year the Welsh Regional service was divorced from the West of England programme, the Welsh programmes being provided by one of the two transmitters at Washford (and by Penmon in North Wales) and those for the West of England by the other transmitter at Washford and by low-power transmitters at Plymouth and Bournemouth. A high-power transmitter at Stagshaw was opened in October, 1937, to serve the North-East of England, replacing the low-power transmitter at Newcastle. A new medium-power transmitter at Redmoss near Aberdeen replaced the old Aberdeen transmitter in September, 1938. In addition to these medium-wave transmitters, several new short-wave transmitters and an extensive system of aerial arrays were constructed on the Daventry site and were first used for the Coronation broadcasts in May, 1937. Programmes in Arabic have been broadcast daily from Daventry since January, 1938, and programmes in Spanish and Portuguese since March, 1938. Work is in progress on a new 100-kW transmitter at Start Point in Devon and a medium-power station at Clevedon, near Bristol, which together will give a Regional programme service to listeners along the south coast from Cornwall to Sussex and an improved service in the south-west of England.

In order to provide increased and improved studio accommodation a new group of studios had already been opened at Maida Vale in October, 1934. Since then new studio centres have been provided at Bangor, North Wales (December, 1935), Swansea (October, 1937), and Glasgow (November, 1938). The Glasgow studio centre incorporates the latest improvements in construction, treatment, and equipment; there are 10 studios, one being the second largest in the country. New studio buildings are under construction in Belfast and in Aberdeen.

Synchronization of Transmitters

Before the beginning of the period under review the increased number of transmitters to be accommodated in the limited number of wavelength channels available in the medium-wave band allocated to broadcasting had already made it imperative to develop methods of synchronization to enable two or more transmitters to work on the same wavelength. It was found that even if two synchronized transmitters always radiated the same programme, the area lying midway between them was poorly served because of interference between the waves received from the two sources. This interference was caused partly by phase differences and partly by small differences between the actual frequencies of the two transmitters. A considerable reduction in the size of this area was effected by increasing the accuracy of synchronization. At first synchronization was effected by transmitting a low-frequency tone over Post Office lines from one station to another, the frequency of this tone being a definite sub-multiple of the carrier frequency of the transmitters. It was multiplied again at the driven transmitters to provide the actual carrier frequency of the group. This method suffered from certain disadvantages: it was necessary to use a network of lines interconnecting the synchronized transmitters, solely in order to carry the synchronizing tone: any slight alteration in the attenuation of these lines caused a severe disturbance in the programme received at a point in the area where the ratio of the field strengths of the two transmitters was not greater than about 5 to 1. The first disadvantage was overcome in some cases by superimposing the driving tone on the line which carried the programme, but the frequency of the driving tone had to be chosen so as to be just within the band transmitted by these lines; at the same time filters had to be provided at the receiving end to exclude the tone from the programme. Special precautions, such as the use of tuning-fork filters and oscillators, were taken to minimize the effect of line variations and induced line noise.

---

* A review of progress.

† British Broadcasting Corporation.

There has, however, been a steady improvement in the frequency stability of individual transmitters. This has been brought about by the growing use of temperature-controlled quartz crystal oscillators. The following Table, based on measurements made at the Brussels checking centre of the U.I.R.,* shows how great the improvement has been:—

FREQUENCY STABILITY OF EUROPEAN BROADCASTING TRANSMITTERS

Maximum variation from mean frequency, c./sec.	Number of stations in:				
	Aug. 1934	Aug. 1935	Aug. 1936	Aug. 1937	Aug. 1938
0 – 1	3	7	20	21	25
1·1–2	3	10	17	16	27
2·1–5	9	23	26	46	26
5·1–10	8	17	16	21	32
0–10	23	57	79	104	110
0–50	42	93	114	138	143

This improvement in frequency stability has made it possible to dispense with the driving tone formerly used for synchronizing and to drive the individual transmitters of a synchronized group by independent quartz crystals. It is, however, still necessary to transmit a synchronizing tone from one transmitter to another for short periods each day so that the frequency can be checked and, if necessary, restored to the correct value. The Welsh Regional and Penmon transmitters have used this method with success for more than a year, and more recently the London, North, and Scottish National group has been changed from tuning fork to independent quartz-crystal drives. The stability of the master crystal at the Welsh Regional station has been found to keep within 0·5 c./sec. over a period of some months—on a carrier frequency of 804 kc./sec. With modern methods of synchronization the ratio of wanted to unwanted signal can be as low as 2 to 1 in field strength.

Design of Transmitting Stations

Before the beginning of the period under review the general increase in the power of transmitters had made the cost of electrical energy a factor of economic importance. Efforts have, therefore, been made to increase the ratio of the output power to the total power consumed by the station. A simple way of achieving this object is to vary the amplitude of the carrier in accordance with the depth of modulation; this system has the effect of operating the automatic gain control on receivers.

Many proposals for high-efficiency modulation systems have been made, and the following are amongst those which have received the most attention—the "High Power Class-B," the "Doherty," the "Chireix," and more recently the "Fortescue," systems.

In the first of these the modulator consists of a high-power low-frequency amplifier with two valves or groups of valves working in push-pull and biased so as to work in the Class-B condition. The average H.T. current thus varies with the depth of modulation, so that the average power consumption is considerably less than the peak power consumed. The modulated valves are driven in such a way as to give maximum efficiency, and modulation is applied to the anodes of the modulated valves through a transformer.

A disadvantage of this form of Class-B system is that a very large l.f. transformer, a large choke, and a large condenser, are needed to carry the high power in the output of the modulator stage. In the Fortescue system this necessity is eliminated by using two banks of h.f. valves in the final stage, one carrying unmodulated high frequency and the other giving an h.f. output proportional to the programme input and working on the Class-B principle. By means of a special impedance-inverting network, the outputs of these two banks are combined to give a normal modulated output. In effect, one bank provides the carrier and the other the sidebands. The bank which supplies the carrier operates at maximum efficiency with a h.f. input, while the other which supplies the sidebands, being a Class-B stage, also works economically.

In the Doherty system there are also two banks of valves, both of which are driven by a normal modulated valve. The first, however, is driven in such a way that in the modulated state the anode peak voltage is almost equal to the H.T. voltage, so that the valves operate at high efficiency. On one half of the modulation cycle the valves amplify linearly, but on the other they limit severely. The other bank is so biased that it is inoperative until the first is beginning to limit, after which it supplies the current necessary to produce a normal modulated output. An impedance-inverting network is again used in order to combine the outputs of the two banks. The system relies upon the balance of the curvature due to the limitation of the valves in the first bank against that due to the bottom bend of those in the second bank.

The Chireix system uses two banks of valves in push-pull, to the grids of which (in series) the modulated h.f. voltage is applied. In addition, a slightly modulated h.f. voltage is applied to the two grids in parallel. This "pilot" voltage does not appear in the output, but by suitably arranging the relative phases it is possible to ensure that the output voltage of each bank is nearly constant throughout the modulation cycle and of such a value that the valves work at maximum efficiency. The output from the two banks is combined in such a way that the two phase-modulated outputs are made to provide a single amplitude-modulated output.

The Class-B system of high-efficiency modulation is in use at the new transmitters at Stagshaw and Redmoss and in two of the new short-wave transmitters at Daventry. In the case of Stagshaw the ratio of the h.f. power output to the total power consumed by the transmitter is about 0·325, compared with about 0·22 for the older system of modulation at low power levels.

---

* The International Broadcasting Union—L'Union Internationale de Radiodiffusion.

The Doherty system of modulation is in use for two 50-kW stations of the Canadian Broadcasting Corporation, while the Chireix system is used in several broadcast transmitters on the Continent, notably in France.

The question of aerial design for medium-wave stations has also become more important, since the range of broadcast transmitters working on high power is usually limited at night by the interference produced between the directly propagated wave and the indirect wave reflected from the ionosphere, rather than by the weakness of the received signal in comparison with the level of interference at the receiver. It is, therefore, necessary to endeavour to increase the effectiveness of the propagation of the direct wave and to reduce that of the indirect ray. Mast radiators having a height equal to about 0·55 times the wavelength had proved efficient in this respect before the beginning of the period under review. Masts of slightly less height can be made effective by the addition of a metal ring at the top, the capacitance of which tends to make more uniform the current distribution up the height of the mast at the frequency of the carrier. Mast radiators have been constructed in this country at Lisnagarvey, Burghead, Penmon, Stagshaw, Aberdeen, Start Point, and Clevedon, and they are in use at most of the recently constructed stations abroad. At Budapest the highest mast of this type in the world has been in use for some years. Its maximum height is 1 030 ft. and it is intended for a carrier wave of 546 kc./sec.

Improvements have also been made in the design of the feeder lines which connect the transmitters to the aerials and in the coupling circuits at each end of the feeder lines. The present practice of the B.B.C. is to use concentric copper-tube feeder (supported above the ground) for medium- and long-wave stations, and open-wire feeders for short waves.

Further improvements in transmitters have included better protection against lightning and the use, for short waves, of variable-inductance tuning.

Studio Design

During the period under review certain changes have been made in the method of acoustically treating the internal surface of studio walls. It is still the general practice in this country to make the structure of the walls as solid and non-resonant as possible by using thick brickwork and avoiding steel reinforcement, which would tend to transmit sounds from one room to another. But, whereas it was frequently the custom to cover the wall surfaces with "building board" firmly fixed to them, a number of other materials are now more favoured as a means of obtaining a satisfactory reverberation time as a function of frequency. Improved methods of measurement have shown that building board is not absorbent enough at the lower end of the audible scale, although this effect is sometimes masked by unavoidable resonances in the structure. Panels of wood or lath and plaster have been used for several years, but have recently become more generally popular. These panels are fixed to wood battens on the solid walls in the normal manner, and their resonant properties cause them to absorb sound energy at the lower frequencies. This treatment is frequently combined with ordinary hard plaster, rock wool, and building board, the proportions of the surface covered by the different materials being adjusted to give the desired reverberation time characteristics.

It is now generally agreed that the distribution of these materials in the studio is important, and it is usual in orchestral studios to concentrate the less absorbent surfaces at the end of the studio in which the orchestra is placed and the more absorbent at the opposite end. Practical experience in the use of serrated surfaces for the walls and ceilings of studios has shown that such shapes do in fact tend to eliminate standing waves and to ensure a uniform sound field. The cost of elaborate shapes is, however, excessive and the result of doubtful benefit. Some breaking-up of wall and ceiling surfaces appears to be desirable, but studios with flat, non-parallel walls have given results almost identical with those obtained from rectangular ones. It has, however, been found desirable to provide a tiered platform at one end of each orchestral studio; this not only enables the microphone to pick up the sound waves from each instrument directly without interference from obstructions, but can be made to provide useful acoustic absorption at the lower frequencies with reflection at the higher frequencies. Incidentally it provides a better arrangement of the orchestra from the conductor's point of view. Floors of hardwood strips on battens are also used for similar reasons.

Low-Frequency Equipment

Important developments have taken place in the design and use of microphones of the "ribbon" or "velocity" type; so much so that they have become standardized for use in all B.B.C. sound broadcasting studios. Two new types of ribbon microphones have recently been developed. One is a smaller form of the original model for use in outside broadcasts and in studios, and the other is a "lip" microphone for the use of commentators in noisy surroundings.

In Germany condenser microphones are still widely used, and a single-sided form has been developed which has proved especially useful. In the United States the ribbon microphone has been adopted as standard by the principal broadcasting organizations, although moving-coil and piezo-electric microphones are also used.

A new type of audio-frequency volume meter has been designed which indicates the magnitude of rapid peaks of modulation and conforms to an international specification which has been adopted by the U.I.R. In the U.S.A., broadcasting organizations continue to use volume meters which indicate "mean syllabic" power rather than peak values. In this they follow the practice of the telephone companies, which find this type of meter economical and satisfactory for use on long lines both for ordinary telephone and for broadcast transmission. Several types of automatic volume-limiter and volume-compressor have also been developed, both in this country and in the U.S.A. Experience in the use of limiters in practice shows that, by eliminating the danger of over-modulation from momentary excessive peaks, they permit an increase in the mean level of modulation without appreciable risk of audible distortion.

Improvements in low-frequency equipment generally have resulted from the increased use of the principle of negative feedback and from the use of multi-electrode valves. Improvements are being made in the technical arrangements for controlling, supervising, and switching programmes. The increasing popularity and importance of outside broadcasts have necessitated the design of improved portable equipment for amplifying and monitoring programmes at outside broadcast points. The art of handling such broadcasts reached a high degree of complexity and reliability during the series of broadcasts which were undertaken at the time of the Coronation. On that occasion two special control rooms were established, one in Westminster Abbey for the Home and Empire programmes, and another in the Middlesex Guildhall through which the special commentaries to foreign countries passed.

Sound Recording for Re-Broadcasting

Advances made in magnetic sound recording on steel tape were described in a recent paper* before the Wireless Section of The Institution. This system has proved of great value in short-wave broadcasting systems, where it is often necessary to repeat a programme several times within 24 hours for reception at convenient listening periods in different parts of the world. The recording can afterwards be effaced from the steel tape, which can thus be used many times for different programmes.

Improvements have also been made in the technique of recording on metal discs coated with a preparation of cellulose acetate. There are now many variations of this method in use in various countries. A new system of electro-mechanical recording on specially prepared film has been installed in London by the B.B.C. and in the stations of several broadcasting organizations overseas. Improvements in the equipment used for reproducing both acetate discs and ordinary gramophone records have been made by the B.B.C. so as to facilitate the editing of a number of excerpts from different recordings to form a continuous programme. These improvements include the use of parallel tracking pick-up arms, of electro-mechanical devices for automatically lowering the pick-up on to the record at the moment when the control potentiometer is faded up, and of special methods of synchronizing the end of one record with the beginning of another so as to facilitate continuous reproduction.

Exchange of Broadcast Programmes

A number of improvements have been made in the transmission of broadcast programmes over lines belonging to the telephone administrations in this and other countries; but this subject does not come within the scope of this review. The number and quality of programmes exchanged between the broadcasting organizations of different countries over lines or radiotelephone services has very greatly increased during the period, those in which this country has taken part having trebled in number.

Short-Wave Broadcasting

During the period under review there have been outstanding developments in short-wave broadcasting in all the principal countries of the world.

In this country a service was established at Daventry in 1932 after initial experiments with a transmitter installed at the works of Marconi's Wireless Telegraph Co., Ltd., at Chelmsford. At first there were only two transmitters at Daventry, each of 10–15 kW. They were provided with 12 directional aerial arrays and 6 omni-directional aerials. The service at that time was directed to 5 zones, but it soon became apparent that reception of particular transmission was by no means confined to the zone for which it was primarily intended.

In 1933 the service was reorganized on a time basis, there being 5 transmissions each at a time suitable for reception at a convenient hour in a given part of the world. Later the vertical aerials were replaced by high horizontal dipoles. In 1935 the experimental transmitter was transferred from Chelmsford to Daventry to provide a third transmitter there, and a sixth transmission was added, so that the service now operates for about 18 hours out of the 24.

In 1935 it was decided to use aerials having a narrower angle of transmission in the horizontal plane; it was also decided as far as possible to provide simultaneous transmission on at least two wavelengths for each zone. In order to fulfil these requirements, two high-power transmitters were completed in 1937 and one in March, 1938. Two more are under construction, intended primarily for a service in foreign languages. Thus 6 transmitters are at present working at Daventry, 3 of 50 kW, 1 of 20 kW, and 2 of 10 kW; the two new ones which are under construction will be ready for use early in 1939 and then 5 transmitters at Daventry will each be capable of an output of 100 kW, although they will actually work on 50 kW in accordance with the licence granted by the Postmaster-General.

The design and construction of a new aerial system consisting of 25 different arrays was completed in 1937, and an open-air switching frame was provided to give increased flexibility in the interconnection of the aerials and transmitters. A central drive room is at present being installed to accommodate all the primary frequency standards required for the station and their associated equipment. The output from any one crystal unit can be connected to any transmitter at will.

The service was fully described in a paper by Messrs. L. W. Hayes and B. N. MacLarty which was read before The Institution during the present session.

The study of propagation conditions, which is of fundamental importance to a successful short-wave service, has been assisted by the inauguration of a reporting scheme by which selected observers in each of the regions to be served sends a weekly cable describing reception conditions. These cables, together with the comprehensive log sheets sent by a larger number of listeners, enable seasonal changes in wavelength to be made at the most opportune moment according to the conditions prevailing in the ionosphere.

General Growth of Short-Wave Services

Similar developments have been going on in other countries, notably Germany and Italy, in both of which countries the radiating systems are in general similar to those at Daventry and consist of stacked horizontal dipoles.

---

* A. E. BARRETT and C. J. F. TWEED: *Journal I.E.E.*, 1938, vol. 82, p. 265.

At Zeesen, the German short-wave broadcasting station, there are 8 transmitters each giving a power output of 50 kW, whereas at Prato Smeraldo, the Italian station near Rome, there are two 100-kW transmitters of similar design to those at Daventry, one 50-kW transmitter similar to those at Zeesen, and two other 50-kW units.

At Zeesen, the feeder system between the transmitters and the aerials consists of articulated concentric cable, while the aerial switching system consists of a motor-operated commutator which gives rapid means of selecting the required aerial array and connecting it to the required transmitter. There have been developments in many other countries, notably in France, the United States, and Holland, while in most European countries some form of overseas short-wave broadcasting is now in regular operation.

At Huizen in Holland a novel form of aerial is in use in which the whole system of two self-supporting masts and the stacked vertical dipole aerial array carried by them is mounted on a turntable on rails so that the beam can be oriented in any desired direction.

Frequency Measurement

In order to ensure the success of international plans for the allocation of broadcast wavelengths there must be an accurate check on the frequency of each transmitter. There are official centres for the measurement of the frequencies of wireless transmitters generally, such as that maintained by the General Post Office at Baldock and that operated by the Bureau of Standards in America. In order to supplement these services in the field of broadcasting and to encourage its members to strive for greater accuracy in the frequencies of their stations, the International Broadcasting Union has maintained a measuring centre at Brussels for a number of years. In 1938 this was moved to a new building specially designed for the purpose and comparatively free from electrical interference. This centre, by virtue of the recognition of the U.I.R. as an " expert " body at the Lucerne and Cairo Conference, works in close co-operation with the administrations concerned in all countries. The precision of measurement at the U.I.R. station is now 2–3 parts in 10^7, and about 600 measurements of long-, medium-, and short-wave broadcasting stations are made every day. In case of any serious departure of a station from its normal frequency the director immediately warns the broadcasting organization concerned.

This U.I.R. checking station is a practical example of useful international co-operation, for the money for its building and equipment has been subscribed by the broadcasting organizations of about 25 countries in the European region and by one of the American networks.

A similar task is performed by the B.B.C. receiving station at Tatsfield which keeps a particularly close watch on B.B.C. stations and others which may interfere with them. Two sets of accurate measuring apparatus are in use. Each of the two basic standards consists of a temperature-controlled quartz-crystal oscillator; the newer one, which has recently replaced an older model, gives a single frequency of 1 000 kc./sec. and has a computed accuracy of ± 4 parts in 10^9. This frequency controls multi-vibrators which produce sub-multiples 1 000 c./sec. apart. A low-frequency oscillator is used, when necessary, to interpolate between these intervals by producing beats with the audible note produced by the measured carrier and the nearest sub-multiple of the standard. The accuracy of the frequency standard is compared every 24 hours with Greenwich time signals by means of a synchronous clock driven by one of the component frequencies derived from the multi-vibrators. Measurements are made on all B.B.C. long- and medium-wave transmitters three times a day, on all B.B.C. short-wave transmitters at least once during every transmission, and on all European medium- and long-wave transmitters once a week. In addition, between 100 and 200 measurements of short-wave stations overseas are made every day, and special checks are made on complaints of interference. Close co-operation is maintained with the Post Office and with the checking centre of the U.I.R. in the elimination of interference between broadcasting stations. The maximum error of measurement at Tatsfield has decreased during the period under review from about ± 1 part in 10^6 to about ± 2 parts in 10^7. In favourable cases the accuracy may be that of the standard, i.e. ± 4 parts in 10^9.

Reception

At the beginning of the period under review the use of the supersonic-heterodyne principle was restricted to the more ambitious receivers, whereas to-day some of the least expensive models incorporate it. Similarly, provision for reception in the short-wave band was not widespread in 1934, and most listeners desiring to receive short-wave programmes used convertors or adaptors. To-day, however, most receivers include at least one short-wave band, many covering reception of the 14-metre (21·5 Mc./sec.) band or even of the sound channel of the London television station (41·5 Mc./sec.). The increasing interest in short-wave listening is indicated by the growing use of receivers of the so-called " Communications " type.

Automatic gain control has become practically universal, whereas automatic tuning correction is still only comparatively rarely included.

A development which has shown a remarkable rise in popularity is " push-button tuning "; in fact, it is interesting to observe that its popularity, as represented by the number of models upon the market, has increased much more quickly here than in the United States. The three systems most commonly used are:—

(*a*) Electric motor drive of the usual multi-unit tuning condenser.

(*b*) Selection by means of pre-set tuning condensers.

(*c*) Selection by means of pre-set tuning inductors.

Ease of tuning has received considerable attention, quite apart from " push-button " operation, and several systems of " band-spreading " are now current practice. Tuning by varying the permeability of the cores of inductances, instead of by variable condenser, is now frequently used.

More attention is now paid to quality of reproduction than formerly, although it appears to be difficult to improve the results obtained from the best examples of table receivers, which are admittedly less satisfactory than those having larger cabinets. Two or three years ago there was a tendency to use two or more loudspeaker units to provide an adequate output throughout the desired range of frequencies, but this requirement can now be met by the use of single loudspeakers of improved design.

The efficiency of output valves has been improved and many receivers are available with single output valves for which an undistorted output of 5 watts is claimed. Signal-frequency amplifying stages are now commonly used with supersonic heterodyne receivers, and for this purpose the special types of tetrodes and pentodes developed for use in television receivers are particularly suitable.

Electrical Interference

A paper* read before The Institution by Messrs. Gill and Whitehead set forth the present state of the campaign against electrical interference. Briefly, the work which has so far been carried out has enabled the British Standards Institution to formulate specifications for the tolerable limits of interference on medium waves and long waves, for the components of interference-suppressing devices, and for the design of apparatus for measuring the strength of interfering voltages and interfering fields. Work is continuing on the suppression of the interference caused to short-wave broadcasting and to television by electro-medical equipment and by the ignition systems of motor-cars. Methods have already been elaborated for reducing the interference so caused. Considerable attention has also been paid to the design of receiving equipment so as to reduce its susceptibility to interference.

International Regulations Affecting Broadcasting

The International Telecommunications Conference which met in Cairo in February and March, 1938, has approved a number of changes to the current radio-communication regulations drawn up at the Madrid Conference in 1932. The allocation of wavebands to the various kinds of radio services has been revised, and the new allocation should take effect from the 1st September, 1939.

No change has been made in the so-called " long wave " broadcasting band, which remains as 160–265 kc./sec. (1 875–1 132 m.), with the existing restriction that the location of stations using frequencies at the higher-frequency end (240–265 kc./sec.) should be in the more outlying parts of Europe. The medium waveband has been extended at the higher-frequency end by 60 kc./sec., becoming 550–1 560 kc./sec. (545–192·3 m.), giving some 6 additional broadcasting channels. Receivers covering the new waveband below 200 m. will be necessary in countries to whose stations these channels may be allotted.

Provision has been made in the Cairo Regulations for the first time for broadcasting in the intermediate waveband 150–60 m. Its use is limited to tropical or semi-tropical regions (between 30° N and 30° S lat.) where the high noise-level due to atmospherics prevents to a great extent the use of the normal medium- and long-wave bands, and where there has been as a result a tendency for stations intended mainly for local service to use frequencies in the short-wave bands below 50 m., intended for long-distance communications only. The new wavebands are:—

2 300–2 500 kc./sec. (130·4–120 m.)
3 300–3 500 kc./sec. (90·9–85·7 m.)
4 770–4 965 kc./sec. (62·9–61·2 m.)

Certain territorial restrictions (especially in America) and limitations of power are, however, imposed.

An additional 500 kc./sec. has been provided for short-wave broadcasting between 50 and 13 m., there having been no change since the original allocation by the Washington Convention of 1927. The wavebands become:—

6 000–6 200 kc./sec. (50–48·39 m.), an increase of 50 kc./sec.
7 200–7 300 kc./sec. (41·67–41·10 m.), a new band of 100 kc./sec. open to broadcasting, except in America, but shared with amateurs.
9 500–9 700 kc./sec. (31·58–30·93 m.) an increase of 100 kc./sec.
11 700–11 900 kc./sec. (25·64–25·21 m.), unchanged.
15 100–15 350 kc./sec. (19·87–19·54 m.), unchanged.
17 750–17 850 kc./sec. (16·90–16·81 m.), an increase of 50 kc./sec.
21 450–21 750 kc./sec. (13·99–13·79 m.), an increase of 200 kc./sec.

The band of 1 000 kc./sec. at about 11·5 m. remains unchanged.

Until the Cairo Conference the allocation of wavebands to the principal services stopped at the higher-frequency end at 28 000 kc./sec. (10·71 m.). With the advent of television and the increased use of ultra-short waves for air navigation and other purposes, the Cairo Conference decided that some regional allocation allowing development to some extent on the same lines in each country was required. An allocation of the ultra-high-frequency bands, to apply throughout Europe, has accordingly been made as far up as 200 Mc./sec. (down to 1·5 m.). The bands allotted for television services are:—

40·5–58·5 Mc./sec. (7·41–5·13 m.), 64–70·5 Mc./sec. (4·69–4·25 m.), 85–94 Mc./sec. (3·53–3·19 m.), 170–200 Mc./sec. (1·76–1·5 m.).

The Madrid Convention of 1932 was followed by a European Governmental Conference at Lucerne in 1933 for the purpose of establishing a wave plan among European broadcasting stations. The Lucerne Plan remains in force, although its allocations in the long-wave band were not accepted by a number of countries, mainly because the number of long-wave stations existing or projected entailed an insufficient separation between them in the waveband available. The existing allocations in the long-wave band mainly follow the temporary plan drawn up by the International Broadcasting Union (U.I.R.) at the end of 1933, which, although in some respects unsatisfactory, has afforded a *modus vivendi* for the existing long-wave stations.

The Cairo Conference issued instructions for the holding of a European Conference to revise the Lucerne Convention, taking into account the changes in the wavebands effected by the new regulations. This is to be concluded in time to allow the plans to be put into force at about the same time as other changes arising from the Cairo Conference. The International Broadcasting Union was charged with the task of preparing, at a meeting to be held at Brussels in the autumn of 1938, a draft plan of allocations for consideration by the European Governmental Conference to be held in Switzerland before the 1st February, 1939.

---

* *Journal I.E.E.*, 1938, vol. 83, p. 345.

Amongst other provisions the Cairo Regulations have fixed new and more strict standards for the permissible limits of frequency tolerance to be observed in the case of all types of radio stations. The tolerance for short-wave broadcasting stations installed after the 1st January, 1940, has been reduced from 0·01 % to 0·005 % (5 parts in 100 000).

Previous to the Cairo Conference, the fourth meeting of the International Consultative Technical Committee for Radio Communications (C.C.I.R.) was held at Bucharest in July, 1937, and recommendations, some of them revising the "avis" of previous meetings, were made on a number of technical questions of international importance. Those which were of interest from the broadcasting aspect included such subjects as single-sideband working, the use of anti-fading aerial systems, the limitations of harmonics, the propagation characteristics of the various orders of wavelengths, taking account of both seasonal and diurnal variations, and precise figures for the frequency tolerance recommended for application by the various types of transmitters. This last recommendation after some modification was embodied, as mentioned above, in the Radio Regulations approved at Cairo.

PART 2. TELEVISION BROADCASTING

General

The report of the Television Committee appointed by the Postmaster-General was issued in January, 1935, and recommended that the B.B.C. should be responsible for establishing a public high-definition television service using ultra-short waves. Experimental transmissions were radiated in August, 1936, and the Alexandra Palace station was formally opened by the Postmaster-General in November, 1936. A regular programme service has been in continuous operation since that date. At first two different standards of transmission were used, but in February, 1937, a single standard was adopted on the advice of the Television Advisory Committee.

According to this standard (i.e. of the Marconi-E.M.I. television system) the picture is scanned with 405 lines at 50 frames per second, the frames, each of 202½ lines, being interlaced to give 25 complete pictures per second. The peak value of the carrier wave, at 100 % modulation, corresponds to a full-white picture area, while 30 % peak carrier value corresponds to full black. The remaining portion of the carrier, that is from 30 % modulation to zero, is used for the synchronizing signals. This form of modulation is sometimes referred to as "positive" and is in the opposite sense to that used in the U.S.A., where the black level corresponds to about 70 % peak modulation, the white level to zero, and the synchronizing signals to 100 % modulation. The Television Advisory Committee has decided that the London television standards shall remain in force for at least 3 years from the beginning of 1938.

The nominal hours of transmission are now from 3 to 4 p.m. and from 9 to 10 p.m.; there is also a morning transmission intended for the purpose of demonstrations and tests by the radio trade.

The vision transmitter and the studio and control room equipment at the Alexandra Palace station are in accordance with the system developed by the Marconi-E.M.I. Television Co. A number of improvements have been introduced during the two years since the opening of the service; in particular an improved type of Emitron tube, known as the long-gun type, is now in use for studio work, while for the transmission of film the continuous-motion film projector has replaced the type employing the standard shutter type of film projector, with improved results. In the case of broadcasts from places remote from the studio, and in particular for sporting events, a further type of Emitron tube, known as the super-Emitron, has been introduced which makes it possible to obtain satisfactory results with telephoto lenses.

The range of the transmitter is considerably greater than was at first expected, and satisfactory reception is possible up to a radius of about 30 miles except in localities where interference is very severe. In exceptional cases reception has been reported at distances up to 200 miles.

Transmitters

The system of transmission was described in papers* read before The Institution last session. The vision transmitter gives a peak output power of 17 kW, and the sound transmitter is rated at 3 kW carrier power or 12 kW peak power at 100 % modulation. The vision transmitter has linear frequency and phase characteristics up to 3 Mc./sec. The carrier frequency of the vision transmitter is 45 Mc./sec, and that of the sound transmitter 41·5 Mc./sec.

Studios

A second studio at Alexandra Palace has now been equipped as a separate unit with its own control room and producer's control gallery. The construction of a third and much larger studio is under consideration. This studio will have 5 main stages and a control tower, from which the producer and the engineers in charge of microphone-mixing and camera-mixing will have a clear view of all the stages.

A new central control room has been equipped with fading and monitoring apparatus to assist in maintaining continuity between the various parts of the programme which come from different sources. To this room will come programmes from the three studios and outside broadcasts which arrive at Alexandra Palace either by way of the balanced-pair television cable or by the ultra-short-wave link.

The central control room has also been equipped with timing-pulse generating equipment, which is used to synchronize the control pulse generators associated with each of the three studios. An advantage of this arrangement is that it becomes possible to mix the vision output of the three studios.

---

* *Journal I.E.E.*, 1938, vol. 83, pp. 729 and 758.

Outside Broadcasts

A great deal of attention has been devoted to television outside broadcast equipment. Three different methods are available for conveying the vision signals from the outside broadcast point to the transmitter at Alexandra Palace, and a combination of more than one of these methods is sometimes necessary. Two complete mobile units are available to provide an ultra-short-wave link working on a frequency of 64 Mc./sec. Each unit consists of four motor vehicles, one containing the vision transmitter (which gives a peak power of 1 kW), one the scanning and monitoring apparatus, one the power supply equipment, and one carrying the fire-escape ladder which supports the transmitting aerial. Special balanced-pair television cables have been installed by the Post Office between Broadcasting House and Alexandra Palace and also between many of the principal centres in London and Broadcasting House. Where this cable is available the radio link is unnecessary and only the scanning van and possibly the power supply van are required.

The range of the special cable can be extended by the use of the third available method, which consists of using ordinary pairs in Post Office telephone cables. Recent work has shown that by careful equalization of the frequency characteristic such pairs can be successfully used to send vision signals over a maximum distance of 4 miles. In this case it is necessary to use special terminal equipment and two intermediate line repeaters, with equalizers, installed at Post Office exchanges along the route. It is, however, unnecessary to interfere with the lines themselves.

Television Overseas

In the U.S.A. a great deal of experimental work has been done, but technical and financial problems still delay the opening of a regular service for home viewers. It is intended to demonstrate television to the public at the New York World Fair in April, 1939, and both the Columbia Broadcasting System and the National Broadcasting Co. will be transmitting television programmes for public reception, the latter from the transmitter situated in the Empire State Building and the former from a new transmitter which is being erected in the Chrysler Building. These vision transmitters work on frequencies of the order of 50 Mc./sec. (6 m.) and deliver a peak output power of 25 to 30 kW to the aerial.

In Germany a 180-line television service has been operated in Berlin for several years, but receivers were not available to the public for home use, viewing facilities being provided in public viewing rooms. A 180-line television telephone service between Berlin and Leipzig has been available to the public since March, 1936, with an extension to Munich in the summer of 1938, but it was only at the beginning of November, 1938, that a public television service, using 441 lines interlaced, 25 pictures per second, was opened on a regular schedule in Berlin and receivers made available for home reception.

In France public demonstrations of television have been carried out from an experimental station at the Eiffel Tower for several years, but high-definition transmissions did not start until the Paris Exhibition in 1937. The new high-definition transmitter has a peak power of 30 kW and works on a frequency of 46 Mc./sec. (6·53 m.). Regular transmissions are now made and receivers are available for home reception. Four different systems of transmission are being used experimentally, no one system having been selected as a standard at the present time (December, 1938).

Experimental work is being done in a number of other countries, notably in Holland where an experiment has been made using 567 lines interlaced at 25 pictures per second.

There is one aspect of television development which must be recorded with regret, and that is that there seems no likelihood of international standardization with regard to definition and picture frequency standards. It is true that no serious attempt has been made so far to bring this about, but the unfortunate fact remains that the standards at the moment are different in the following countries:—

	Lines per picture	Pictures per second	Modulation
America . .	441	30	Negative
Germany . .	441	25	Positive
Great Britain . .	405	25	Positive
France	Various between 440 and 455	25	Positive

It may be that in the distant future international television cables may become available, and then the absence of a common standard for European countries might become a serious matter.

THE DESIGN AND CONSTRUCTION OF A SHORT-WAVE FIELD-STRENGTH MEASURING SET*

By F. M. COLEBROOK, B.Sc., and A. C. GORDON-SMITH.

(*Paper first received* 22*nd August, and in final form* 19*th October,* 1938.)

SUMMARY

The paper contains a discussion of the principal features of the design of apparatus for the measurement of field strength at very short wavelengths by means of a loop aerial. The apparatus consists of a high-gain intermediate-frequency amplifier (about 1 Mc./sec.) associated with a signal-frequency and frequency-change unit of constant conversion efficiency. The e.m.f. of thermal agitation in the input tuned circuit of the intermediate-frequency amplifier is used as a standard signal for setting the amplifier to a known gain. The combination of intermediate-frequency amplifier and signal-frequency unit is calibrated over its signal-frequency range by means of a radiator which gives a horizontally-polarized radiation of calculable intensity.

It is shown that a single-phase, i.e. unsymmetrical, frequency-change system has certain practical advantages over biphase systems, and that this can be used without loss of the necessary balance of the aerial system, if the latter is coupled inductively through a Faraday screen to the frequency-change circuit. The detailed design of the various couplings and of the diode frequency-conversion circuit are analysed in Appendices.

The intermediate-frequency amplifier embodies continuously-variable gain-controls, calibrated in decibels, these components being a particular type of commercial carbon-track " volume control " which has been found satisfactory for this quantitative use.

The set can be used for the measurement of field strengths down to the order of microvolts per metre at wavelengths from 7–11 metres (27–43 Mc./sec.) with the frequency-change and aerial units described.

(1) THE TECHNIQUE OF SHORT-WAVE FIELD-STRENGTH MEASUREMENT

There are at present two principal methods of measuring an unknown field-intensity: (*a*) the measurement of the voltage produced by the unknown field in some suitable form of aerial, and the subsequent calculation of the corresponding field-intensity in terms of the constants of the aerial; (*b*) the comparison of the unknown field-intensity with a known field-intensity by means of some form of transfer instrument—in practice, an aerial and a receiving set.

The first method involves a radio-frequency voltmeter of very high sensitivity, i.e. capable of the measurement of potential differences of the order of microvolts. In practice this means an amplifying radio-frequency receiver of very high gain, the amplitude calibration of which is determinable by the application of a known small voltage of signal-frequency to its input terminals, or in series with the aerial connected to its input terminals. Until a few years ago, some form of this method was the only one employed in practice, but its reliable application was limited to measurements of fields with wavelengths greater than about 15 metres, owing to the technical difficulties of the calibration process referred to at wavelengths shorter than this. Recently, however, there has been produced by a well-known firm an equipment in which the range of application of this method has been extended to about 3 metres.

A theoretically possible variation of the first method is a combination of a high-gain intermediate-frequency amplifier, the performance of which is readily determinable by known methods, with a signal-frequency collector and frequency-change unit of directly calculable performance. The authors attempted a design based on this scheme, chiefly in order to secure an independent check of the second or known-field method. The attempt failed, for reasons which are themselves of sufficient interest to justify the following brief account.

The signal-frequency unit consisted of a symmetrical loop aerial, directly coupled to a frequency-change unit, which, to preserve symmetry and to eliminate " antenna effect in the loop aerial, must be of the biphase or push-pull type. The effective height of the loop aerial (i.e. $2\pi \times$ area turns divided by wavelength) was calculated, and its Q or resonance-factor ($\omega L/R$) determined by a reactance-variation method. Considering now the frequency-change part of the unit, it is shown in Appendix III that the quantitative relationships of frequency conversion by means of a diode circuit are theoretically very simple and are amenable to direct measurement. The circuit finally employed is illustrated in Fig. 1, but in a first construction the oscillator voltage was mistakenly introduced into the common lead in series with the tuned intermediate-frequency circuit. An examination of the theory of such a circuit shows that, assuming perfect symmetry, the output intermediate-frequency voltage should have been zero. In practice the output obtained was so large that the error in the circuit was overlooked for some while. This led to a more systematic examination of the extent to which the postulated symmetry could in fact be realized at very short wavelengths. A unit was constructed in which two intermediate-frequency circuits were incorporated, with zero mutual inductance between them. The first was arranged as shown in Fig. 1, and the second in the position shown as the local-oscillator

---

* Official communication from the National Physical Laboratory.

The Papers Committee invite written contributions, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Contributions (except those from abroad) should reach the Secretary of The Institution not later than one month after publication of the paper to which they relate.

coupling in Fig. 1, the local-oscillator coupling being transferred to the common lead. With perfect symmetry the whole of the intermediate-frequency output would appear across the second circuit, none appearing in the first. It was found that although all normal steps were taken to ensure electrical symmetry, the output in the wrongly connected circuit was nearly twice as great as that in the correctly connected circuit. Even with an auxiliary 3-plate balancing condenser of small capacitance, introduced as shown in Fig. 1, the necessary complete symmetry was not obtained, for the output in the wrongly connected circuit was not reducible below about half of that given by the other. It was thus apparent that very elaborate precautions would be required, combined with some degree of auxiliary balancing by additional variable impedances, in order to realize to an adequate extent the electrical symmetry postulated in the simple theory. In view of these experiments it seemed doubtful whether a directly calculable equipment would in fact be realized with sufficient certainty to justify its use as an independent check of the known-field method. The attempt was therefore abandoned, and this brief account is only included for information in relation to any future work on these lines, and as a warning against the too-facile assumption of actual electrical symmetry in apparently symmetrical dispositions at very short wavelengths.

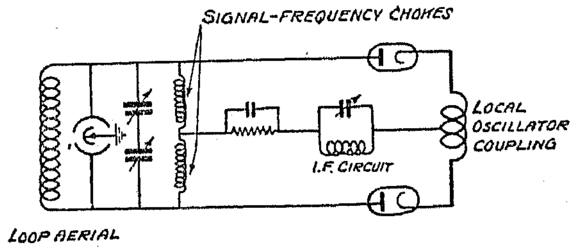


Fig. 1.—Biphase or "push-pull" diode frequency-change circuit.

The second method depends essentially on the calculation of the field intensity produced by some simple form of radiator in terms of the physical constants of the radiator (in practice, a closed-loop aerial), the current in the radiator, the electrical constants of the ground, and the disposition of the point of measurement and the radiator relative to each other and to earth. The method was originally introduced when measurements on the shorter wavelengths became of commercial importance, as a way out of the difficulty already mentioned in connection with the first method. In its earliest form, e.g. as described by Schelling, Burrows, and Ferrell,* the technique involved some elements of uncertainty owing to the difficulty of making accurate allowance for the effect of the earth. Recently, however, an important advance has been made in this field by J. S. McPetrie and B. G. Pressey, who have called attention to the valuable simplifications which are introduced into the underlying theory by the use of horizontally polarized waves instead of the vertically polarized waves originally employed. Indeed, with this simplifying modification it may be argued that the standard-field method, at least in the range from, say, 15 metres downwards, is as free from technical and theoretical uncertainties as the alternative, or standard-microvolt, method, and can therefore claim at least as high a status in practice even though in theory it may be one stage further removed from the fundamental standards.

The apparatus described in the present paper is intended for use in conjunction with a standard-field radiator as described by McPetrie and Pressey.* The intention of the design is, however, that a single calibration of this kind over its working range (7 to 11 metres) should suffice. That is to say, the high-gain intermediate-frequency part of the equipment is adjustable to a standard condition by reference to the e.m.f. of thermal agitation in the input intermediate-frequency tuned circuit, and the signal-frequency part is designed for inherent constancy within practical limits.

It is desired to emphasize that the apparatus is described primarily for the information of those working in this field, and not as a standard and perfected equipment, and the description is therefore more concerned with the principles involved than with the detail of this particular assembly.

(2) GENERAL DESCRIPTION

The equipment consists of a unit comprising a tunable frame aerial, a frequency-change oscillator, and a diode frequency-conversion circuit. This unit is coupled by means of a concentric screened lead to a second unit consisting of a high-gain intermediate-frequency amplifier and rectifier. The tuning range of the signal-frequency unit is from 7 to 11 metres (43 to 29 Mc./sec.), and the intermediate-frequency amplifier is tuned to 250 metres (1·2 Mc./sec.). The necessary voltage supplies are derived from a dry battery (120 volts) and accumulator (4 volts) contained in a separate wooden box, with plug-in connectors to the two units. The normal disposition of these units is shown in the photograph (Fig. 2). The units are described in detail below.

(3) THE SIGNAL-FREQUENCY UNIT

(a) Aerial

In a previous paper,* one of the authors has analysed the behaviour of single-turn aerials in relation to direction-finding and field-strength measurement on short wavelengths. For present purposes, the most important conclusions are:—

(i) If the lowest point of such a loop aerial is connected to earth or to a point having appreciable capacitance to earth there will be, in general, even if the coil and tuning system are electrically and geometrically symmetrical, appreciable current flowing in such connection and it is desirable that this shall not affect the terminal potential-difference of the aerial. Thus, if the aerial is tuned by a three-terminal symmetrical condenser at the bottom of the loop, it is desirable that the receiver shall record the vector sum of the potential differences across each half of the tuning condenser. In a symmetrical system, this vector sum will be independent of any current flowing in the earth or "earthy-point" connection. Alternatively, and preferably, the aerial can be so connected as to have a maximum of impedance to earth at its electrical centre.

---

* See Bibliography, (1).

* See Bibliography, (2).

† *Ibid.*, (3).

(ii) It is not essential that the periphery of the loop shall be small compared with the wavelength of operation, i.e. it is not essential that the current in the loop shall be uniform throughout the length of the loop. It appears that for peripheral lengths less than about a quarter of the wavelength of operation, neither the induced e.m.f. nor the polar-distribution of "effective height" is very sensitive to current distribution. If necessary, the effect of non-uniform current-distribution on the induced e.m.f. can be calculated and allowed for, but if, as in the present case, the set is calibrated by a standard field radiator, the effect of current distribution on effective height does not enter into the matter. If a substantially uniform vertical polar-distribution of reception-sensitivity is desired, the peripheral length should not exceed about one-fifth of the wavelength of operation.

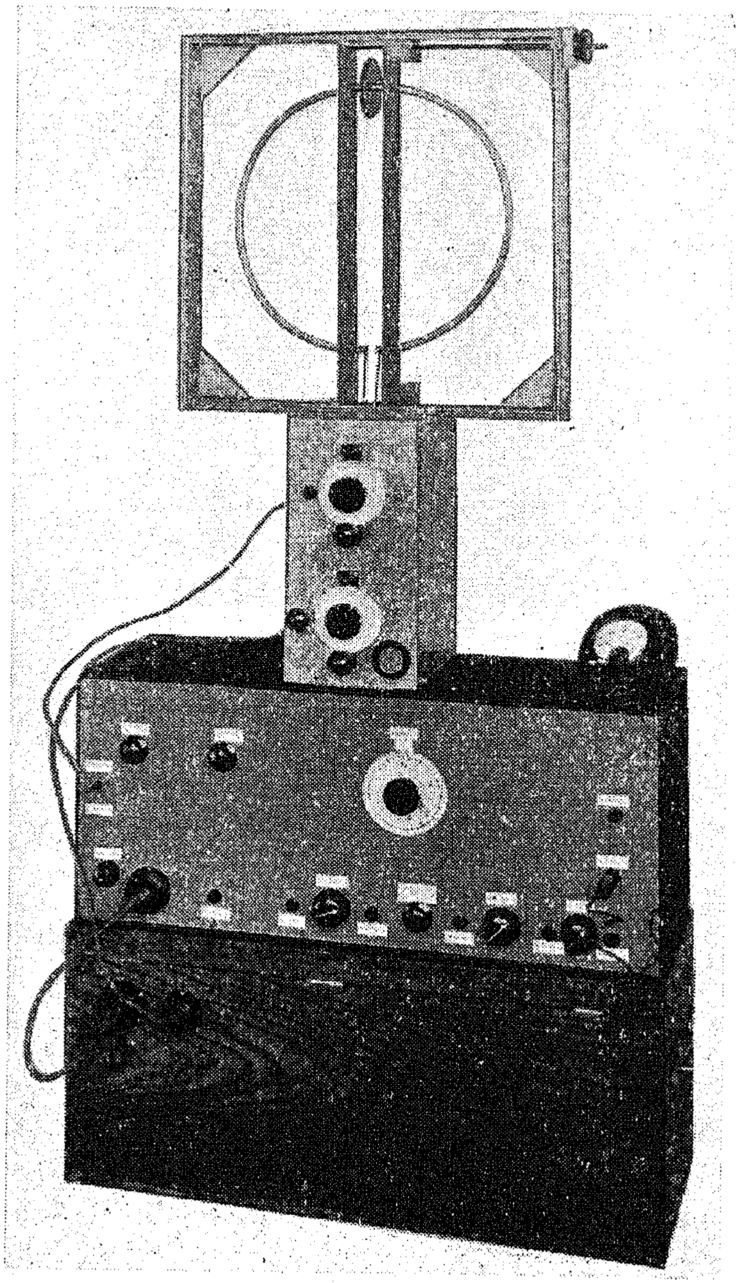


Fig. 2

A practical point of some importance is that the aerial shall have a minimum of "pick-up" with respect to waves of frequencies in the region of that of the intermediate-frequency amplifier. For this reason the coupling of the aerial to the receiver should be as loose as possible consistent with signal-frequency efficiency.

A means of satisfying these various requirements is illustrated schematically in Fig. 3. The aerial is tuned by a variable capacitance at the top of the loop (a system adopted in the commercially-produced equipment already referred to) and is inductively coupled to a closed secondary circuit, with a metal screen between the windings. A convenient screened coupling was obtained by metallizing the external cylindrical surface of a ribbed ceramic coil-former (the ribs being left unmetallized); the secondary was wound externally on the ribs of the former, and the small single-turn coupling coil was inserted inside. The coil former was mounted so that its upper open end was against the roof of the metal screening case, as indicated in Fig. 3. (The metal case in this model was constructed of tinned iron of fairly heavy gauge. In a later model, copper plate is being used.)

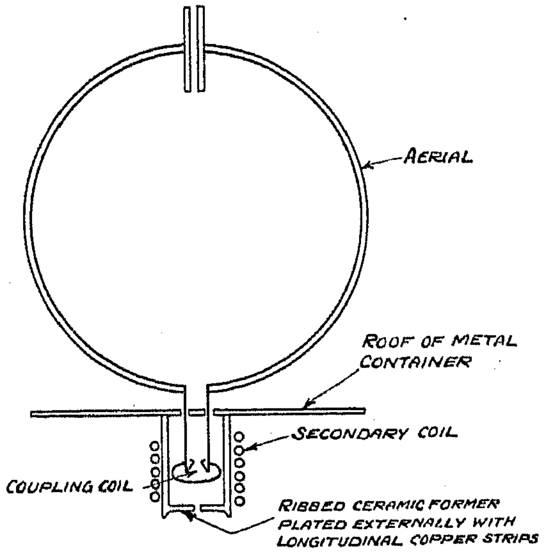

AERIAL
ROOF OF METAL CONTAINER
SECONDARY COIL
COUPLING COIL
RIBBED CERAMIC FORMER PLATED EXTERNALLY WITH LONGITUDINAL COPPER STRIPS

Fig. 3.—Assembly of loop aerial, screened coupling, and secondary coil.

It is shown in Appendix I that the optimum value of the coefficient of coupling is given by

$$k = \sqrt{(p_1 p_2)}$$

where p_1 and p_2 are the "power factors" of the aerial and secondary circuit respectively. The optimum is not critical, and can be approximated to by trial. It cannot in any case be realized at all frequencies in the range, and the condition to be aimed at is that the coupling shall not be appreciably below the best value at any point.

An important advantage of the screened coupling system described is that it avoids the necessity for biphase or "push-pull" frequency-conversion. That is to say, it enables a single-phase or unsymmetrical frequency-conversion circuit to be used without impairment of the essential symmetry of the loop-aerial system. The

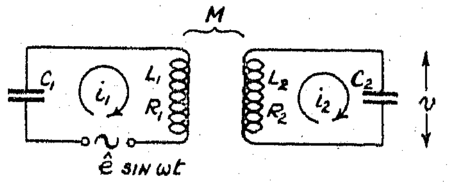


Fig. 4

difficulties associated with symmetrical valve circuits at very short wavelengths have been referred to in Section (1).

It must be noted that the tuning process with these loosely coupled tuned circuits is not, unfortunately, a simple matter of adjustment of the two tuning condensers in turn. Referring to Fig. 4, for any setting of C_1 there will be a tuning value for C_2, but C_1 must then be displaced one way or the other and C_2 retuned, this being repeated until the absolute optimum is reached.

The type of aerial loop used in this and other models has proved very satisfactory. It will tune over an unusually wide range of wavelengths (at least 3·5 : 1), minimizes dielectric loss, and is comparatively simple in construction. In the present model it consists of two semi-circles of copper tube, mounted so that one of the semi-circles hinges at the bottom. The tuning condenser consists of two brass discs soldered directly on to the top ends of the two semi-circles. The end of a threaded ebonite rod presses against the plate soldered to the pivoted semi-circle, and tends to close the gap against the tension of a rubber band.

(b) Frequency Conversion

It was decided to use a diode frequency conversion circuit, for the following reasons:—

(i) Linearity.

With a sufficiently large voltage from the frequency-change oscillator, diode frequency conversion is linear with respect to signal voltage, and the intermediate-frequency output is substantially independent of oscillator voltage. This is a valuable feature from the point of view of maintenance of calibration.

(ii) Quantitative relationship.

It is shown in Appendix III that the quantitative relationships involved are comparatively simple.

(iii) Harmonic operation.

It has been shown by Strutt[*] that in diode circuit frequency-conversion with a large oscillator voltage (5 volts or more), the conversion efficiency using the second or third or even higher-order harmonics of the oscillator output in the diode circuit should not be materially less than for the fundamental. The use of harmonics in this way has advantages in respect of "pulling" and interaction of controls. In the present model the fundamental is actually used for the normal range, but it was found possible to extend the range downwards to about 4 metres by short-circuiting part of the closed secondary circuit and using the second harmonic of the oscillator output.[†]

The circuit finally adopted, after considerable experiment, is shown in all essentials in Fig. 5. The coupling condenser C_1 is intended to lessen the load of the diode on the closed secondary circuit by a kind of matching process. It can be shown that if the effective resistance of the diode is R_d and the dynamic resistance of the tuned circuit is R_c, the optimum value of C_1 is

$$\frac{1}{\omega\sqrt{[R_d(R_c - R_d)]}}$$

At very high frequencies this is, in general, a very small quantity, e.g. with $R_d = 10^4$ and $R_c = 2 \times 10^4$, $C_1 = 0 \cdot 4\ \mu\mu\text{F}$ (approximately) at 7 metres. The best value will in practice exceed this calculated value on account of the anode-to-cathode capacitance of the diode, but will generally be less than 1 $\mu\mu$F. For the present model a length of "styro flex" tubing was slipped over a short piece of wire, which was then inserted in a brass tube of about 2 mm. bore, making a tiny variable concentric-cylinder form of condenser.

Condenser C_3 is similarly a matching condenser for the intermediate-frequency load circuit. The frequency being lower (about 1·2 Mc./sec.), a somewhat larger value is appropriate.

The frequency-change oscillator is coupled to the diode by means of the small capacitance C_2. In practice it was found that sufficient coupling for an induced diode-circuit voltage of 5 or 6 volts was obtained by mounting a short straight wire along the length of the oscillator coil and about $\frac{1}{4}$ in. away from it. Various other forms of coupling were tried, including "electron" coupling, using an "acorn" pentode valve as the oscillator and coupling valves, but the arrangement shown in Fig. 5 was found to be the most satisfactory in respect of both "pulling" and available amplitude. The smallness of the capacitance C_1 contributes materially to the success of this mode of coupling.

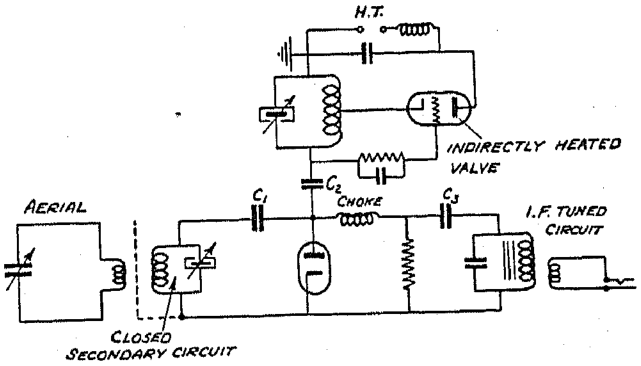


Fig. 5.—Circuit diagram of aerial and frequency-change unit.

The oscillator circuit used is a somewhat unfamiliar but very useful variant of the Hartley circuit, made possible by the use of an indirectly heated valve. The oscillatory circuit is essentially in series with the supply voltage and the valve, and chokes are therefore not essential for oscillation. Further, one electrode of the tuning condenser can be earthed. In practice, a choke can be inserted in the H.T. lead, but this is merely to restrict the flow of radio-frequency current in the supply leads.

The intermediate-frequency coil is wound on a small iron-dust core, and is provided with a secondary winding of a few turns for matching the tuned impedance to the surge impedance of a concentric screened line for coupling to a similar tuned circuit in the intermediate-frequency amplifier. In general, a short screened coupling lead is used and the signal-frequency unit stands on the intermediate-frequency amplifier, as shown in Fig. 2. If desired, however, a longer coupling lead can be used and the signal-frequency unit can be remote from the intermediate-frequency amplifier. It was found that the matching was sufficiently good to give substantially the same output with the long as with the short coupling lead.

---

[*] See Bibliography, (4).

[†] Since the present paper was written, further field-strength measuring equipments for use at wavelengths down to 1 metre have been developed by the authors. The circuits employed are essentially the same as those described in the present paper, with tuned dipoles and "flex" transmission-line couplings in place of the tuned loop aerial. Diode-circuit frequency-conversion in the harmonic mode of operation has been used throughout and has proved satisfactory. The calibration at 3 metres was checked after some months of field use and was found not to have changed materially.

An " acorn " triode valve is used for the oscillator circuit, and a similar valve, with anode and grid connected, is used as the diode. (The set was constructed prior to the recent introduction of certain very small diode valves, now commercially obtainable, which would otherwise have been used.)

(4) THE INTERMEDIATE-FREQUENCY UNIT

The circuit diagram of the intermediate-frequency amplifier is shown in Fig. 6. It comprises four stages of amplification by means of radio-frequency pentode valves, a diode rectifier with an auxiliary diode for optional automatic gain-control, and a balanced 2-valve bridge-type output circuit. The tuned frequency is about 1·2 Mc./sec.

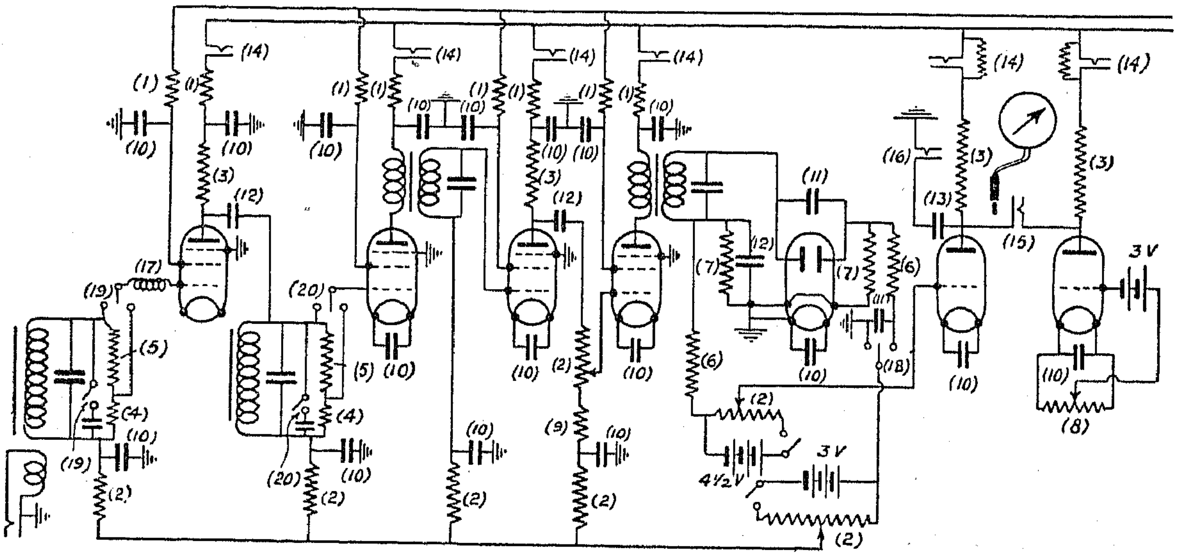


Fig. 6.—Circuit diagram of intermediate-frequency units.

(1) 5 000 ohms.
(2) 10 000 ohms.
(3) 20 000 ohms.
(4) 500 ohms.
(5) 100 000 ohms.
(6) 100 000 ohms.
(7) 1 000 000 ohms.
(8) 1 000 ohms.
(9) 500 ohms.
(10) 0·1 μF.
(11) 0·001 μF.
(12) 0·01 μF.
(13) 2 μF.
(14) Test plug.
(15) Output plug.
(16) Telephone plug.
(17) Radio-frequency choke (7–10 m.).
(18) Switch for A.V.C.
(19, 19) } Double-pole
(20, 20) } 2-way switches.

Many features of the design and assembly are quite normal. Only special and distinctive features will be described in detail.

(a) Use of Battery Valves

Battery valves are used for the sake of weight economy in voltage supplies. Special precautions are, however, required to eliminate interaction by way of filament circuits. Each filament is short-circuited by a 0·1-μF condenser and is connected to the common 2-volt supply by a separate twisted pair. There remained, nevertheless, a slight residual instability, which, for reasons not yet understood, disappeared when the by-pass condenser was disconnected from the first valve. It cannot be stated that the means adopted are in fact the best general means for preventing filament-circuit interaction, but they proved sufficient in the present case.

(b) Buffer Stages

There is much to be said for the use of resistance-coupled buffer stages interposed between tuned-circuit stages, even with screened valves. The first and third stages are of this kind, though a relatively flat tuned circuit is used in the first in place of a grid resistance, mainly to minimize the effect of the input capacitance on the attenuator step which is located at this point.

(c) Attenuators

There are three attenuator stages—34 and 50 db. in single steps—and a continuously variable stage of 38 db. maximum. The single-step attenuations are obtained by means of resistances connected across the first- and second-valve input tuned circuits. Double-pole 2-way switches are used, one way introducing a small preset capacitance to maintain the tuned condition when the input capacitance is removed from across the tuned circuits in the " attenuator in " position.

The continuous variation of attenuation is obtained by means of a carbon-track variable resistor of 20 000 ohms (maximum). It is a commercially obtainable type in which the moving arm makes contact by means of three separately-acting metal-spring brushes. Preliminary examination had shown that the contact so obtained is sufficiently good, definite, and reproducible for quantitative use and calibration to an order of accuracy adequate for the present purpose (1 or 2 per cent). It has obvious advantages over the alternative of fixed resistors and a multi-way step switch, and has proved quite satisfactory in practice. A small fixed resistance is connected in series, to improve the law and limit the range to about 40 db.

(d) Rectifier Circuits

The rectifier is arranged in such a way as to produce a reduction in the anode current of the output valve when a signal is received. The chief practical advantage of this arrangement is that it limits the current through the output instrument, which can never exceed the initial steady anode current of the output valve. This is about 1·5 mA, so that the maximum possible overload on the 500-μA output instrument is only 3 times full scale.

It was found necessary to derive the automatic-gain-control voltage from a separate anode in the double-diode rectifier, to prevent minute grid currents in the amplifying valves from affecting the grid potential of the output valve. This separation of functions also facilitates control of the output/input law with automatic gain control.

(e) Output Circuit

A bridge circuit is used, with independent control of the grid bias of each valve. The output instrument (0–500 μA) is not permanently attached, but is connected to a plug. The same instrument is used for inspection, shunts being permanently wired across the plug points where necessary.

The preliminary adjustment of the output circuit is carried out as follows: The instrument is plugged into the anode circuit of the last (balancing) valve and the anode current adjusted to a scale reading of 500 μA (an actual value of 1·5 mA). The instrument is then plugged into the working position and, with full attenuation in, the deflection is reduced to zero by adjustment of the grid bias of the output valve. This procedure ensures constancy of initial current in the output valve.

(5) OPERATION AND CALIBRATION

(a) Adjustment of Intermediate-frequency Amplifier

The intermediate-frequency amplifier is adjusted to a standard gain by the method introduced by the Radio Branch of the Post Office.* The frequency-change unit is first disconnected, and full attenuation is switched in. The output valve circuits are adjusted and balanced as described. The attenuator switches are all set to the minimum value, and the first input tuned circuit is brought into tune with the other tuned circuits. The manual gain control is now adjusted so that the output instrument reads 400 μA, this output being due to the e.m.f. of thermal agitation in the first tuned circuit.

If the first tuned circuit is distuned, or the first attenuator step switched in, the output falls to 90 μA, and is further reduced to practically zero if the first valve is switched out or removed. Thus practically the whole of the noise output of the amplifier (with minimum attenuation) is due to the e.m.f. of thermal agitation in the first tuned circuit, the remainder being due to shot-effect noise in the first valve. This large preponderance of the first-circuit noise is due to the fact that the first circuit is of high dynamic resistance (about 125 000 ohms, with about 100 000 ohms in parallel due to the first attenuator step), and also to the low anode currents of the valves in the standard condition (about 0·2 mA per valve).

(b) Field-strength Calibration and Measurement

The technique of the production of a known field-intensity by means of a closed-coil radidator has been fully described by McPetrie and Pressey.† For present purposes it is assumed that such a known intensity ϵ_0 is available, and that when the set is tuned to it a total attenuation N_0 is required to reduce the output-instrument indication to a certain standard value K (400 μA in the present instance). From the attenuation N giving the same standard output with an unknown field intensity ϵ, the latter can be calculated in the following way.

It will be assumed in the first instance that ϵ and ϵ_0 are so large that the contribution in each case of the "noise" voltage to the standard output is negligible. Then, if a_0 and a be the amplification values corresponding to ϵ_0 and ϵ respectively,

$$\frac{\epsilon}{\epsilon_0} = \frac{a_0}{a}$$

or

$$20 \log \frac{\epsilon}{\epsilon_0} = 20 \log \frac{a_0}{a} = \frac{20 \log (a_0/a_m)}{a/a_m} = N - N_0$$

where a_m is the amplification corresponding to zero inserted attenuation. This gives ϵ as $(N_0 - N)$ decibels above ϵ_0. It will, however, be more convenient to determine, on the above assumption with regard to noise voltage, the theoretical attenuation N_1 corresponding to a field intensity of 1 μV per metre. From the above,

$$N_1 = N_0 - 20 \log \epsilon_0$$

in which ϵ_0 is in microvolts per metre. The field strength ϵ corresponding to an attenuation N is then given directly as $(N - N_1)$ decibels above 1 μV per metre.

For example, from a plot of field intensity against N at 10 metres it was found that, for $N_0 = 50$, $\epsilon_0 = 1{\cdot}880$. Thus

$$\begin{aligned} N_1 &= 50 - 20 \log 1{\cdot}880 \\ &= 50 - 65{\cdot}50 \\ &= -\ 15{\cdot}5 \text{ db.} \end{aligned}$$

The corresponding figures for 9, 8, and 7 metres were − 7·8, − 4·5, and − 4·6 db. respectively.

With such a set of constant numbers for the various wavelengths, the apparatus becomes virtually direct reading in field strengths.

For small values of N (less than about 10 db.) the standard output deflection will be partly due to "noise" —both internally generated and received from external sources. For example, at zero attenuation the output will be about 300 μA, even without additional background noise, due to the e.m.f. of thermal agitation of the first circuit, as modified by its connection to the aerial unit. Thus, in general, at small values of attenuation, the standard output K will fall, not to zero, but to some other value K_1 when the signal is removed. This residue must of course be allowed for in estimating the corresponding field-strength. The appropriate correction will obviously depend on the law of the second rectifier.

A linear rectifier, when excited by e.m.f.'s having r.m.s. values of E_1 and E_2, of different frequencies, gives an output proportional to $\sqrt{(E_1^2 + E_2^2)}$. Thus, for a linear rectifier, the correction required can be estimated by regarding the total standard output K as due to a signal e.m.f. E_s and a " noise " e.m.f. E_n That is,

---

* See Bibliography, (5).

† *Ibid.*, (2).

$$K = k\sqrt{(E_s^2 + E_n^2)}$$

Also
$$K_1 = k\sqrt{E_n^2} = kE_n$$

Therefore the response due to E_s alone is

$$kE_s = \sqrt{(K^2 - K_1^2)}$$

Thus if the calculated uncorrected field-strength is $\epsilon\,\mu$V per metre, the corrected value ϵ_c is given by

$$\epsilon_c = \frac{\epsilon}{\sqrt{[1 - (K_1^2/K^2)]}}$$

or, in decibels,

$$N_c = N + 10 \log \left(1 - \frac{K_1^2}{K^2}\right)$$

Similarly, for a square-law rectifier,

$$\epsilon_c = \epsilon\sqrt{\left(1 - \frac{K_1}{K}\right)}$$

and
$$N_c = N + 10 \log \left(1 - \frac{K_1}{K}\right)$$

In the present case, it was found by calibration that the second rectifier is linear down to about 50 μA output, and can therefore be regarded as linear over the working range.

(c) Analysis of Sensitivity Figures

It will be of some interest to analyse the recorded sensitivity figures. For example, at 7 metres, it is found that the theoretical field intensity for full standard output is $1{\cdot}6\,\mu$V per metre. By calibration with a standard signal generator it is found that full standard output corresponds to $5{\cdot}2\,\mu$V on the first grid.

Let k = frequency-conversion factor;
m_e = overall circuit magnification factor (i.e. ratio of secondary-circuit resonant p.d. to primary or aerial-circuit e.m.f.);
h_e = effective height of aerial coil
= $2\pi \times$ area$/\lambda$;
ϵ = field strength, in volts per metre;
and v = input voltage on first grid of intermediate-frequency amplifier.

Then
$$\frac{v}{\epsilon} = kh_e m_e$$

The aerial coil is approximately 33 cm. in diameter, giving a value for h_e of $7{\cdot}7$ cm. at a wavelength of 7 metres. From the above data,

$$\frac{v}{\epsilon} = 3{\cdot}25 \times 10^2$$

Thus
$$km_e = 42{\cdot}2$$

It is shown in Appendix III that, for a directly connected intermediate-frequency circuit, k should not differ greatly from unity. In the present case, however, there is some degree of matching of the composite load consisting of the two tuned circuits and the transmission-line coupling to the much lower resistance of the diode, and from certain approximate measurements it appears that k is about 3, in which case m_e will be about 14.

It is shown in Appendix I that circuits having m values of m_1 and m_2, inductively coupled to the optimum degree as defined in Appendix I, should give an overall m (or magnification factor) equal to half the geometric mean of m_1 and m_2 times the square root of the ratio of the inductances L_1 and L_2. If it be assumed that an approximation to the optimum coupling has in fact been realized in the present case by the empirical adjustment used, then $(L_2/L_1)^{\frac{1}{2}}(m_1 m_2)^{\frac{1}{2}}$ is about 28. This is a reasonable value, since the secondary circuit is a small coil of about $1\frac{1}{2}$ in. diameter, wound with solid wire, and is, moreover, damped by the diode.

It appears, therefore, that the numerical results obtained are in conformity with design estimates of the quantities involved at each stage.

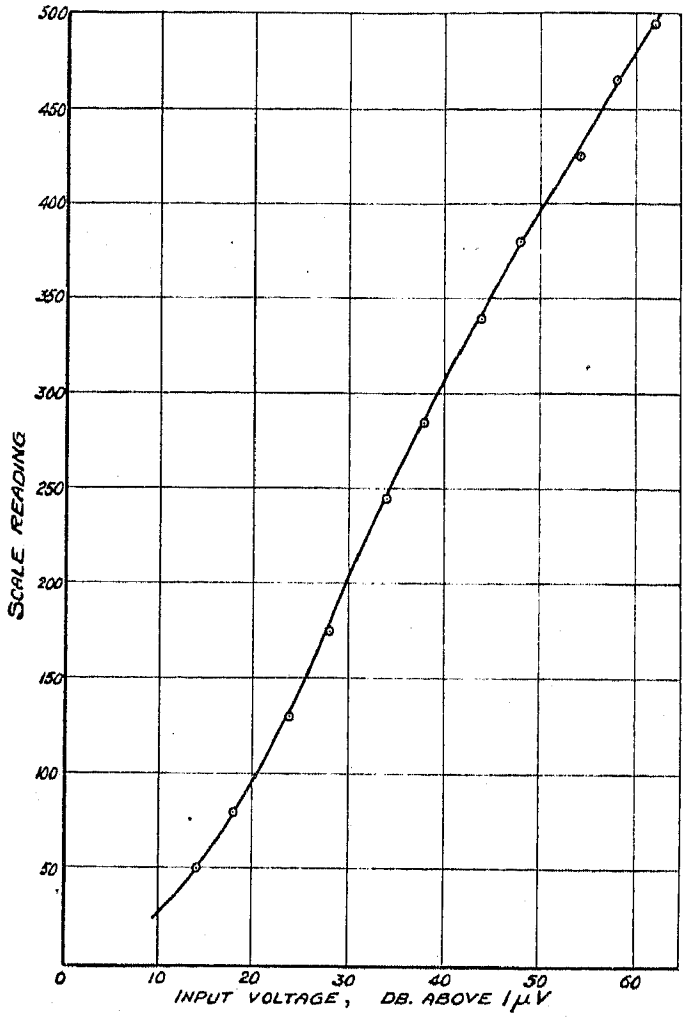


Fig. 7.—Output/input calibration with automatic gain-control.

(d) Operation with Automatic-Gain Control

It will be seen from Fig. 6 that the intermediate-frequency amplifier is provided with means for introducing automatic gain control if desired. This facility may be of some use in making continuous approximate surveys of field strength, e.g. in an aircraft or other moving vehicle. It is intended that the equipment should be used deflectionally in such cases, the automatic gain control enabling a wide range of field strength to be recorded within the limit of full-scale deflection.

The scale may be calibrated in terms of first-grid input-voltage by means of a standard-signal generator, coupled to the input circuit in such a way that the resulting input-circuit tuned impedance is reduced to the same value as is given by the coupling to the frequency-change unit (giving, therefore, the same input noise-voltage for initial adjustment). The actual voltage at the input grid can be determined in terms of the output voltage of the standard-signal generator by a separate measurement of the effect of the coupling, and the grid voltage may be related to field strength by means of the field-intensity calibration, as already described in (*b*) and (*c*), Section (5).

It was found that by switching to automatic gain control, and adjusting to a noise-voltage output of 50 (this initial deflection then being reduced to zero by means of the initial balancing control), a range of nearly 50 db. could be obtained from zero to full-scale deflection. The calibration curve is shown in Fig. 7. It is substantially linear in decibels, except at the lower end, where the co-existent noise voltage causes an apparent lowering of sensitivity.

The range can be extended by introducing a known attenuation by means of the intermediate-frequency attenuators. For example, at an input voltage of 62 db. above 1 μV the output was 495 μA. This was reduced to 130 μA by switching in 38 db. of attenuation in the intermediate-frequency circuit, which agrees exactly with the output for an input voltage of 62 — 38 (= 24) db. above 1 μV from the standard-signal generator.

(6) ACKNOWLEDGMENTS

The authors wish to acknowledge their indebtedness to Dr. J. S. McPetrie for the standard-field calibrations of the equipment described, and to Dr. R. L. Smith-Rose for criticism and advice. The work was carried out as part of the programme of the Radio Research Board, and is published by permission of the Department of Scientific and Industrial Research.

(7) BIBLIOGRAPHY

(1) SCHELLENG, J. C., BURROWS, C. R., and FERRELL, E. B.: " Ultra-Short Wave Propagation," *Proceedings of the Institute of Radio Engineers*, 1933, vol. 21, p. 427.

(2) McPETRIE, J. S., and PRESSEY, B. G.: " A Method of Using Horizontally Polarized Waves for the Calibration of Short-Wave Field-Strength Measuring Sets by Radiation," *Journal I.E.E.*, 1938, vol. 83, p. 210.

(3) COLEBROOK, F. M.: " The Application of Transmission-Line Theory to Closed Aerials," *ibid.*, 1938, vol. 83, p. 403.

(4) STRUTT, M. J. O.: " Diode Frequency-Changers," *Wireless Engineer*, 1936, vol. 13, p. 73.

(5) MUMFORD, A. H., and BARKER, P. I..: " A Field-Strength Measuring Set using Thermal Agitation Noise as the Calibrating Source," *Post Office Electrical Engineers' Journal*, 1935, vol. 28, p. 40.

APPENDIX I

For the inductively coupled system shown in Fig. 4, the transfer vector admittance i_2/e at frequency $\omega/(2\pi)$ is

$$\frac{i_2}{e} = -\frac{M\omega j}{Z_1Z_2 + M^2\omega^2}$$

where $$Z = R + jX = R + j\left(\omega L - \frac{1}{\omega C}\right)$$

That is,

$$\frac{i_2}{e} = -\frac{M\omega j}{Z_1}\,\frac{1}{R_2 + \dfrac{M^2\omega^2R_1}{|Z_1|^2} + j\left(X_2 - \dfrac{M^2\omega^2X_1}{|Z_1|^2}\right)}$$

If M and X_1 are fixed, resonance with respect to X_2, i.e. with respect to the tuning capacitance C_2, is given by

$$X_2 = \frac{M^2\omega^2X_1}{|Z_1|^2}$$

Similarly, if M and X_2 are fixed, resonance with respect to C_1 is given by

$$X_1 = \frac{M^2\omega^2X_2}{|Z_2|^2}$$

For the first of these conditions,

$$\left|\frac{i_2}{e}\right|_{res.} = \frac{M\omega}{|Z_1|}\,\frac{1}{R_2 + \dfrac{M^2\omega^2R_1}{|Z_1|^2}}$$

Regarding this as a function of X_1, it will be found by the usual process of differentiation that two optimum values for X_1 exist, i.e.

$$(a)\ X_1 = \pm R_1\sqrt{\left(\frac{M^2\omega^2}{R_1R_2}\right)} - 1\ \text{(maxima)}$$

$$(b)\ X_1 = 0$$

The first condition can only be fulfilled if the quantity under the radicle is positive. This is a condition of " excessive coupling," and corresponds to the well-known double-peaked resonance as a function of frequency. For this condition, the absolute optimum secondary current is given by

$$\left|\frac{i_2}{e}\right|_{res.} = \frac{1}{2}\,\frac{1}{\sqrt{(R_1R_2)}}$$

The second condition can be fulfilled for all values of M_1 and corresponds to a minimum with " excessive coupling " and a maximum with loose coupling. For this second condition

$$\left|\frac{i_2}{e}\right|_{res.} = \frac{1}{\sqrt{(R_1R_2)}}\,\frac{1}{\dfrac{\sqrt{(R_1R_2)}}{M\omega} + \dfrac{M\omega}{\sqrt{(R_1R_2)}}}$$

The factor involving $M\omega$ has a maximum value of $\frac{1}{2}$ when the two denominator terms are equal, i.e. when

$$M^2\omega^2 = R_1R_2$$

In this case the two optima (*a*) and (*b*) above merge into a single condition. In this condition $X_1 = X_2 = 0$. Putting

$$M^2 = k^2L_1L_2$$

$$k^2 = \frac{R_1}{\omega L_1}\cdot\frac{R_2}{\omega L_2}$$

or $$k = \sqrt{(p_1p_2)}$$

where p_1 and p_2 are the power factors of the two circuits.

Under conditions of optimum coupling, the output voltage v_2 is given by

$$\left|\frac{v_2}{e}\right| = \frac{M\omega + \omega L_2}{R_1R_2 + M^2\omega^2}$$

$$= \frac{1}{2}\sqrt{(m_1m_2)}\sqrt{\left(\frac{L_2}{L_1}\right)} = \frac{1}{2}\,\frac{L_2}{M}$$

where m is written for $\omega L/R$, i.e. the overall " m " is

$m/2$ in the case of optimum coupling of identical circuits, and half the geometric mean of the "m's" multiplied by the square root of the ratio of the inductances in the case of optimum coupling of circuits which differ.

APPENDIX II

Determination of Resistances and Coupling Factor for Loosely-Coupled Tuned Circuits

It is well known that the resistance and the "m" (i.e. $\omega L/R$) of a tuned circuit can be determined by measuring the capacitance-change δC corresponding to the $1/\sqrt{2}$ ordinates of the resonance curve, the formulae being

$$\frac{1}{2\omega}\frac{\delta C}{C^2} = R$$

and $$m = \frac{\omega L}{R} = \frac{2C}{\delta C}$$

In the case of loosely coupled circuits, as illustrated in Fig. 4, assuming that the coupling is purely inductive and is such that

$$M\omega < \sqrt{(R_1 R_2)}$$

(i.e. a loose coupling, corresponding to a single-peaked resonance having an absolute maximum value when $X_1 = X_2 = 0$, as shown in Appendix I), the quantities $R_1 R_2$ and M can theoretically be determined by a somewhat similar process, as follows:—

(*a*) With C_1 constant at the resonance value corresponding to frequency $\omega/(2\pi)$, determine the total capacitance-change δC_2 corresponding to the $1/\sqrt{2}$ resonance ordinates of the secondary-circuit current (or voltage). Then, from the formula (see Appendix I):—

$$i_2 = -\frac{M\omega j}{(R_1 + jX_1)(R_2 + jX_2) + M^2\omega^2}$$

it can be shown that, with $X_1 = 0$,

$$\frac{1}{2\omega}\frac{\delta C_2}{C_2^2} = \frac{R_1 R_2 + M^2\omega^2}{R_1} = \alpha$$

(*b*) With C_2 constant at the resonance value, C_1 varied to give the $1/\sqrt{2}$ resonance values of secondary current (or voltage), we have

$$\frac{1}{2\omega}\cdot\frac{\delta C_1}{C_1^2} = \frac{R_1 R_2 + M^2\omega^2}{R_2} = \beta$$

(*c*) Remove or open-circuit the primary, and determine R_2 in the ordinary way, i.e.

$$\frac{1}{2\omega}\frac{\delta C_2'}{C_2^2} = R_2 = \gamma$$

Then R_2 is known, $R_1 = \beta\gamma/\alpha$, and $M^2\omega^2 = \beta\gamma[1 - (\gamma/\alpha)]$.

Further,

$$\left|\frac{v_2}{e}\right|_{res.} = \frac{M\omega}{\omega C_2(R_1 R_2 + M^2\omega^2)}$$

$$= \frac{1}{\omega C_2}\sqrt{\left(\frac{\alpha - \gamma}{\alpha\beta\gamma}\right)}$$

$$= 2C_1\sqrt{\left[\frac{1}{\delta C_1}\left(\frac{1}{\delta C_2'} - \frac{1}{\delta C_2}\right)\right]}$$

Thus, considering the matter from the point of view of field-strength measurement, if v_2 is known, the effective e.m.f. e induced in the primary or aerial circuit is theoretically determinable by means of a set of three half-resonance measurements. The chief practical difficulties, at least at very high frequencies, would be (i) the determination of the tuning-condenser calibrations (which might, unless the condensers had been specially designed for ultra-short-wave operation, depend appreciably on frequency) and (ii) ensuring that the coupling is of the purely inductive character postulated. A further minor point is that the formulae are only exact in respect of resonances of the secondary current, whereas in practice the secondary resonance voltages would be measured. The difference in the resonance conditions is not, however, very material with reasonably good circuits.

The method was not actually adopted in the present instance, as the tuning condensers used were not suitable for the quantitative calibration involved.

APPENDIX III

Single-Phase and Biphase Diode Frequency-Conversion

Mathematical analysis.

The following is a simplified and approximate analysis of frequency conversion by means of diode rectification, by methods similar to those used by M. J. O. Strutt,* and is intended to give some qualitative insight into the process.

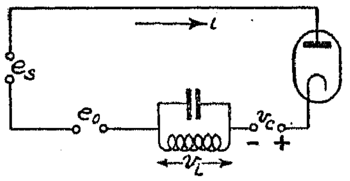


Fig. 8.—Diode frequency-change circuit [characteristic $i = f(v)$].

Consider the circuit shown in Fig. 8, where $e_s = \hat{e}_s \sin \omega_s t$ is a small signal voltage, $e_0 = \hat{e}_0 \sin \omega_0 t$ is a relatively large local-oscillator voltage, v_i is the output intermediate-frequency voltage, and v_c is a direct voltage somewhat smaller than e_0. (It may in practice be derived from a suitably by-passed resistance.) It will be assumed that the only significant external impedance in the diode circuit is the tuned intermediate-frequency (ω_i) circuit, having a dynamic resistance R_i.

Then

$$i = f(e_0 + e_s - v_c - v_i)$$

and, for sufficiently small values of e_s and v_i,

$$i = f(e_0 - v_c) + (e_s - v_i)f'(e_0 - v_c)$$

where $$f'(v) = \partial f/\partial v$$

Bearing in mind the nature of $f(v)$, e_0, and v_c, it will be seen that $f'(e_0 - v_c)$ regarded as a function of time represents a series of pulses of the nature shown in Fig. 9, and as such can be expanded into a Fourier series. Thus

---

* See Bibliography, (4).

$$i = f(e_0 \sin \omega_0 t - v_c)$$

$$+ (\hat{e}_s \sin \omega_s t - v_i) \left[u_0 + u_1 \sin(\omega_0 t + \theta_1) + u_2 \sin(2\omega_0 t + \theta_2) + \ldots\right]$$

where u_0, u_1, u_2, etc., are constants.

In the above it is assumed that $f(v)$ is substantially independent of the frequency of v, which implies a suitable choice of diode at very high frequencies, and that the voltage e_s is maintained without effective internal impedance. Under these conditions the diode-capacitance current plays a negligible role as far as frequency conversion is concerned, and its omission in the above formulation is justified. Equating separately the intermediate-frequency components,

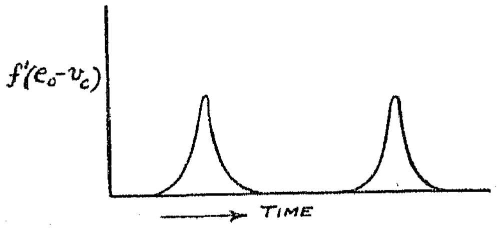


Fig. 9

$$i_i = -u_0 v_i + \hat{e}_s \cdot \frac{u_1}{2} \cos(\omega_i t + \theta_1)$$

where $\qquad \omega_i = \omega_0 \sim \omega_s.$

Putting $\qquad v_i = R_i i_i,$

$$v_i = \frac{R_i}{R_i + \dfrac{1}{u_0}} \cdot \frac{u_1}{2u_0} \cdot \hat{e}_s \cos(\omega_i t + \theta_1)$$

Thus, as far as the intermediate-frequency components are concerned, we have the equivalent circuit shown in Fig. 10.

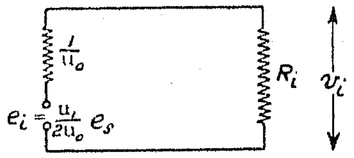


Fig. 10

The general character of the Fourier series must now be considered. Take, for example, the function shown in Fig. 11, where, for simplicity, the pulses are assumed to be the crests of sine waves of fundamental period T_0. It will be found that, for such a function,

$$u_0 = \frac{1}{\pi}(\sin \alpha - \alpha \cos \alpha)$$

$$u_1 = \frac{1}{\pi}\left(\alpha - \frac{1}{2} \sin 2\alpha\right)$$

$$u_2 = -\frac{1}{\pi}\left(\frac{1}{1\,.\,2} \sin \alpha - \frac{1}{2\,.\,3} \sin 3\alpha\right)$$

$$u_3 = -\frac{1}{\pi}\left(\frac{1}{2\,.\,3} \sin 2\alpha - \frac{1}{3\,.\,4} \sin 4\alpha\right)$$

$$u_4 = \frac{1}{\pi}\left(\frac{1}{3\,.\,4} \sin 3\alpha - \frac{1}{4\,.\,5} \sin 5\alpha\right)$$

where $\alpha = \pi\tau/T_0$.

Now if the pulses are narrow, i.e. if τ and α are small, so that $\sin \alpha$ can be replaced by $\alpha - (\alpha^3/6)$, then

$$u_0 = \frac{1}{\pi} \cdot \frac{\alpha^3}{3}$$

and $\qquad u_1 = u_2 = u_3 = u_4, \text{ etc.} = \frac{2}{\pi}\frac{\alpha^3}{3} = 2u_0$

This relationship is likely to hold whatever the shape of the pulse, provided it is sufficiently narrow. Moreover, even if it is an appreciable fraction of a period in width, u_1 will not differ greatly from $2u_0$. For example, if $\tau = T_0/2$,

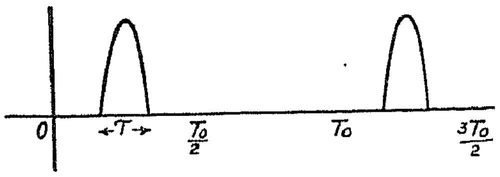


Fig. 11

Then $\qquad \frac{u_1}{2} = u_0 = \frac{\pi}{4} \simeq 0{\cdot}8$

Thus, in the above formula for v_i (the intermediate-frequency output voltage), $u_1/(2u_0)$ can be replaced by unity, and we have the simple relationship

$$\hat{v}_i = \frac{R_i}{R_i + \dfrac{1}{u_0}} \hat{e}_s$$

If, in addition, R_i is large compared with the effective internal intermediate-frequency resistance $1/u_0$,

$$\hat{v}_i = \hat{e}_s$$

This simplicity of theoretical relationship is of some value in relation to such quantitative applications as field-strength measurement. Even when the various postulated conditions cannot be very completely fulfilled, the use of a fairly large frequency-change oscillator voltage and an output circuit of high impedance will probably result in an overall conversion-ratio which does not differ much from unity.

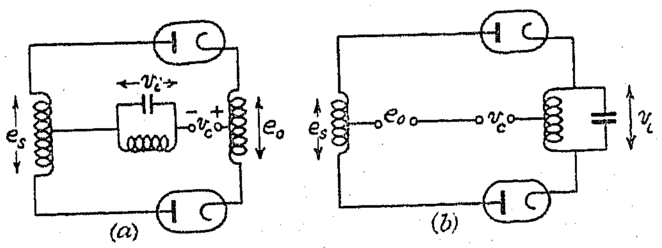


Fig. 12

If any form of direct coupling between the loop aerial and the rectifier circuit is used, the preservation of electrical symmetry will require the use of biphase or push-pull circuits, shown schematically in Fig. 12. The same simplified analysis for such cases gives for the intermediate-frequency output voltage a value just half that for the single-phase circuit.

Use of harmonics.

It has been shown that the fundamental and low-order harmonics of the diode-circuit current are of comparable magnitude. The local oscillator can therefore be adjusted to 2, 3, 4, etc., times the wavelength appropriate to frequency conversion by means of the fundamental, without appreciable loss of conversion ratio. This theoretical conclusion, which was pointed out by Strutt in the paper referred to, is substantially confirmed in practice. The conversion ratios corresponding to the second and third harmonics were found to be approximately equal, though a little less than that corresponding to the best conditions for the fundamental. The difference, which is not more than 3 or 4 db., is unimportant compared with the great advantages of harmonic operation, the chief of which is freedom from interaction between the local-oscillator and signal-frequency tuned circuits. At very short wavelengths there is the additional advantage that satisfactory oscillation is more readily obtainable at the longer wavelengths appropriate to the use of harmonics. A loop-aerial field-strength equipment for use at frequencies up to 300 Mc./sec. has already been constructed on these lines and has been found satisfactory.

Harmonic operation, biphase circuits.

The biphase circuits shown in Fig. 12 are appropriate for harmonic operation using odd harmonics. For even harmonics the oscillator voltage should be induced in the common lead in (*a*), and the output circuit should be in the common lead in (*b*).

ALTERNATING HYSTERESIS LOSS IN ELECTRICAL SHEET STEELS*

By F. BRAILSFORD, Wh.Sc., B.Sc.(Eng.), Associate Member.†

(*Paper received* 31*st August*, 1938.)

SUMMARY

The paper describes a direct method of measuring alternating hysteresis loss in sheet materials utilizing small disc specimens. The loss may be measured in any desired direction in the sheet on the same samples, utilizing simple apparatus. No eddy-current losses are involved in the measurement.

The observed results on four electrical sheet materials are given.

The Steinmetz law is found to hold approximately for the lower portion of the loss curves, and a straight-line law for the upper portion. The change is found to occur near the knee of the magnetization curve where, according to theory, the mechanism of the magnetization process also changes.

A definite correspondence between the loss and magnetization curves for different directions in the sheet is found. It is concluded that hysteresis loss is a function not only of the magnetization but also of the field strength, and a qualitative explanation is given.

The general relation of alternating hysteresis loss in a single crystal of silicon iron to the principal crystal directions is inferred from the observations on one of the samples.

The alternating hysteresis loss is compared with the rotational hysteresis loss previously determined on the same samples. The ratio between them is found to be approximately the same for all the four materials investigated.

INTRODUCTION

In a previous paper‡ a direct method of measuring rotational hysteresis loss in small disc samples of sheet steel was described and the results of investigations on four grades of electrical sheet steel were given. In the present paper a similar, direct method of measuring alternating hysteresis loss in any desired direction in the sheet in disc samples is given, together with the experimental results obtained on the same four samples.

The method of measuring alternating hysteresis loss in a ferromagnetic material by determining the average torque produced by the reaction of a magnetic field on the sample when there is relative rotation between them is well known. In the case of Ewing's "hysteresis tester"§ the sample was rotated and the average torque acting on the field system measured, while Weiss and Planer|| rotated the field system and measured the mean torque acting on the sample. In either scheme the relative speed of rotation has to be such that the alternations of torque occurring during each revolution are averaged out to produce a steady deflection of the measuring system.

In the present case this method of smoothing out the alternating torque has been avoided by using a sample consisting of three equal discs mounted in a particular way in a stationary applied field. It is shown theoretically that, for the electrical sheet materials under consideration up to an induction of about 13 000 gauss, the only torque required to rotate the sample is that corresponding to the hysteresis loss. An alternating torque appears above this, but is not troublesome until much higher flux densities are reached. It is thus possible to make the measurements when the speed of rotation has been brought to zero, which leads to a simplification of the apparatus required and avoids the inclusion of eddy-current losses in the measurements.

The method has the further merit of enabling the loss to be determined for any direction in the sheet relative to the rolling direction on the same small disc specimens. This is a useful feature, in view of present attempts to improve electrical sheet materials by inducing a particular crystal orientation in the sheet. In such materials the magnetic properties may vary enormously, depending on the direction in the sheet in which magnetization is applied. To investigate these variations by methods of measurement utilizing strip samples would require a considerable quantity of material, which is particularly inconvenient where only experimental quantities are available. Precise comparison of the results would, furthermore, be hampered by the fact that observations in the various directions would be made on different samples of the material.

THEORY

Consider a thin disc capable of rotation in a uniform applied field H' about a diameter perpendicular to the direction of the field, as shown in Fig. 1. Neglecting hysteresis and magnetic anisotropy in the material, the effective field H in the material will coincide in direction with the intensity of magnetization J, which will not remain parallel to the plane of the disc, as the disc is rotated, but will be inclined at some angle β to it, as shown.

The field H is the resultant of the applied field H' and the demagnetizing field produced by the magnetization in the disc. It will be supposed that the thin disc approximates to an oblate ellipsoid of revolution and has a demagnetizing factor N in the direction of a diameter, and N_1 perpendicular to the plane of the disc. For a thin disc, N_1 will approximate¶ in value to 4π and N will be small compared with 4π.

---

* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of The Institution not later than one month after publication of the paper to which they relate.

† Metropolitan-Vickers Electrical Company, Ltd.

‡ F. Brailsford: *Journal I.E.E.*, 1938, vol. 83, p. 566.

§ J. A. Ewing: "Magnetic Induction in Iron and other Metals" (London, 1900), p. 379.

|| P. Weiss and V. Planer: *Journal de Physique*, 1908, vol. 7, p. 5.

¶ J. A. Ewing: "Magnetic Induction in Iron and other Metals," p. 31.

Resolving the various components of field along and perpendicular to the diameter, we have

$$H \cos\beta = H' \sin\alpha - NJ \cos\beta \quad . \quad . \quad (1)$$

and

$$H \sin\beta = H' \cos\alpha - N_1 J \sin\beta$$

whence, eliminating β and taking $N_1 = 4\pi$, we find the following relation between J, H, and α, where the flux density is $B = H + 4\pi J$:—

$$\cos^2\alpha\left[1 - \left(\frac{H + NJ}{B}\right)^2\right] = 1 - \left(\frac{H + NJ}{H'}\right)^2 \quad (2)$$

Except near saturation ($H > 1\,000$ gauss, say, for electrical sheets) this approximates to

$$\cos^2\alpha = 1 - \left(\frac{H + NJ}{H'}\right)^2 \quad . \quad . \quad . \quad (3)$$

When $\alpha = 0$ the magnetization in the disc will obviously be a minimum (J_{min}), but not zero, it will be a maximum (J_{max}) when $\alpha = 90°$; whence we may deduce from equation (2) that

$$\frac{J_{min}}{J_{max}} = \frac{N}{4\pi}\left(\frac{H' - H_{min}}{H' - H_{max}}\right) \quad . \quad . \quad . \quad (4)$$

where H_{min} and H_{max} are the effective field-strengths corresponding to J_{min} and J_{max}.

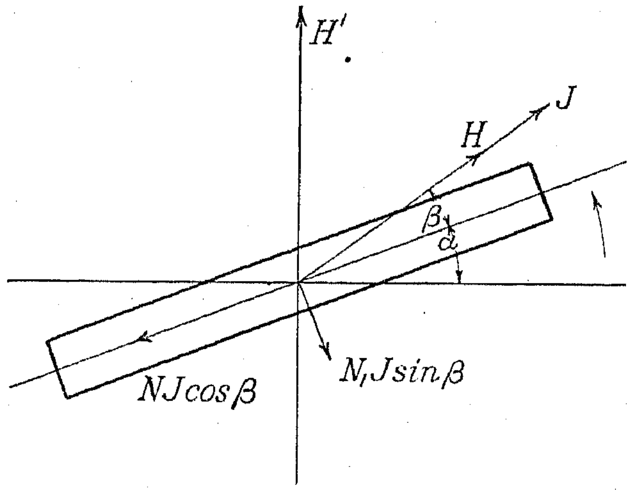


Fig. 1

As the disc is rotated in the field H' the direction of the magnetization J will deviate from the plane of the disc by the angle β and, the relation between J and α having been determined from equation (2), the corresponding values of β can be determined from equation (1).

The numerical values given in the following refer to Sample 1 of ordinary electrical dynamo sheet, for which experimental results are given later. These discs were 1·23 in. diameter, 0·016 in. thick, with $N = 0{\cdot}160$, and the magnetization curve measured in the rolling direction has been used.

Fig. 2 shows the variation of the total magnetization with the angle of rotation of the disc, calculated from equation (3) for $J_{max} = 1\,433$ or $(B - H)_{max} = 18\,000$ gauss. The calculated angle β between the magnetization and the plane of the disc is also shown. It is seen that this angle does not exceed a few degrees, except when J is approaching its minimum value.

Fig. 3 shows J_{min}/J_{max} obtained from equation (4), plotted against J_{max}. It is seen that the magnetization in the disc when it is normal to the applied field is less than 2 % of the maximum intensity up to $(B - H)_{max} = 18\,000$ gauss.

The component of J in the plane of the disc is given by $J_P = J \cos\beta$, and the way in which this varies as the disc rotates is shown in Fig. 4 for a number of values of J_{max}.

Examination of these numerical results indicates that rotation of a thin disc in an applied field in the manner described leads to an almost purely alternating magnetization of the material, the rotational component being unimportant up to, say, in the case of Sample 1, $J_{max} = 1\,600$ or $(B - H)_{max} = 20\,00$ gauss.

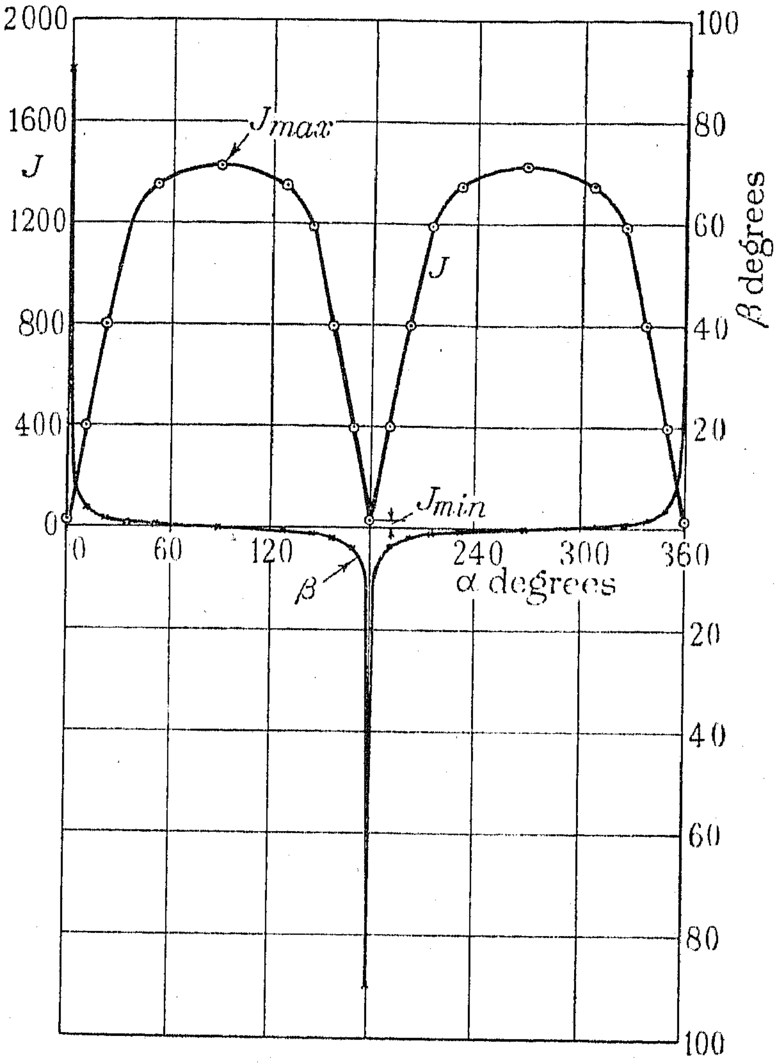


Fig. 2.—Calculated total magnetization J and angle β between J and the plane of the disc for $J_{max} = 1\,433$ or $(B - H)_{max} = 18\,000$ gauss in the case of Sample 1.

Inspection of the curves in Fig. 4 shows that we may write

$$J_P = J_1 \sin\alpha + J_3 \sin 3\alpha + J_5 \sin 5\alpha + \ldots$$

J_3, J_5, and J_7 have been obtained by analysing the curves shown in Fig. 4, and their values are given in Fig. 5.

Now, neglecting the small component of J perpendicular to the disc, the torque per cubic centimetre acting on the disc due to the applied field H' is given by

$$\begin{aligned} l_1 &= H' J_P \cos\alpha \\ &= \frac{H'}{2}\{(J_1 + J_3)\sin 2\alpha + (J_3 + J_5)\sin 4\alpha \\ &\qquad + (J_5 + J_7)\sin 6\alpha + \ldots\} \quad . \quad (5) \end{aligned}$$

If a single disc is rotated through one revolution in the field H', then the applied torque will be required to overcome l_1 together with a torque l_h per cm^3 due to hysteresis loss in the material. The work done in one complete revolution is clearly 2π times the average value of l_h (since the average value of l_1 is zero) and is equal to the alternating hysteresis loss per cubic centimetre per cycle.

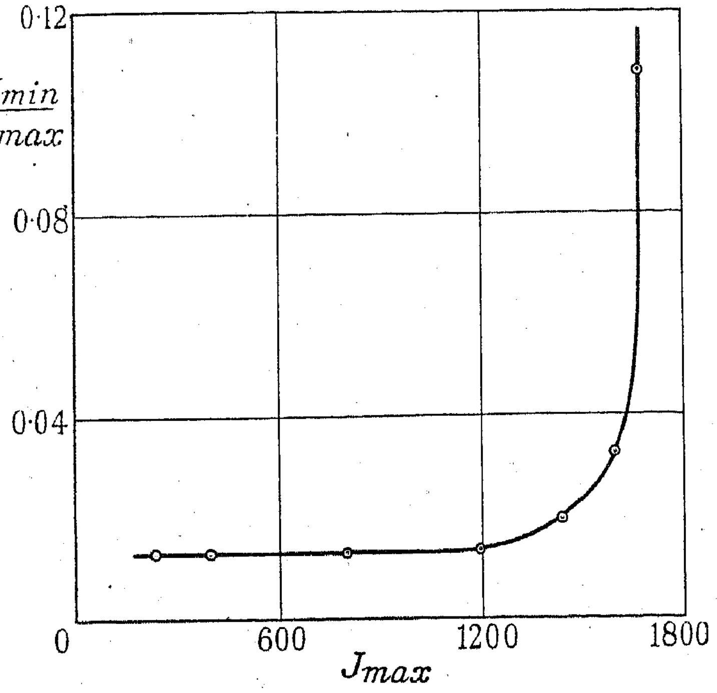


Fig. 3.—Ratio between minimum and maximum total magnetization in a disc of Sample 1 during rotation.

In the case of one of the above discs at $(B - H)_{max}$ = 10 000 gauss we have $J_1 = 799$, $J_3 = J_5 = J_7 = 0$, and $H' = 129 \cdot 5$ gauss, whence l_1 has a peak value of 51 700 dyne-cm. per cm^3. Also, the alternating hysteresis loss at this density is found to be 2 265 ergs per cubic centimetre per cycle, giving l_h an average value of 360 dyne-cm. per cm^3 Thus the mean torque due to hysteresis loss is only 0·7 % of the peak torque due to the reaction between the applied field and the magnetization in the disc. It would therefore not be practicable to measure alternating hysteresis loss by determining the torque curve corresponding to one revolution of the disc in an applied field.

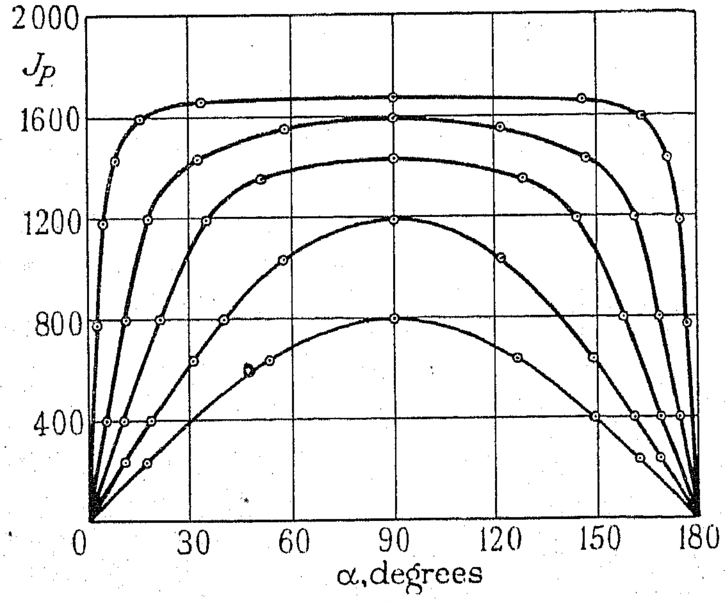


Fig. 4.—Calculated wave-form of component of magnetization J_P parallel to plane of disc during rotation.

The difficulty can, however, be overcome by the use of a number of discs simultaneously. In the general case we require n identical discs mounted one above the other, with corresponding diameters of the discs coinciding with the axis of rotation and with the n discs in n vertical planes inclined successively at $180°/n$ to one another. If these n discs are then mounted in a uniform horizontal applied field H' and rotated as a unit, it is readily shown, referring to equation (5), and neglecting the $(4n - 1)$th and higher harmonics, that the torque per cubic centimetre is given by

$$l = \tfrac{1}{2}H'(J_{2n-1} + J_{2n+1}) \sin 2n\alpha$$

Thus, with two discs inclined at 90° to one another, we have

$$l = \tfrac{1}{2}H'(J_3 + J_5) \sin 4\alpha$$

and with three discs relatively displaced at 0°, 60°, and 120° we have

$$l = \tfrac{1}{2}H'(J_5 + J_7) \sin 6\alpha \quad . \quad . \quad . \quad . \quad (6)$$

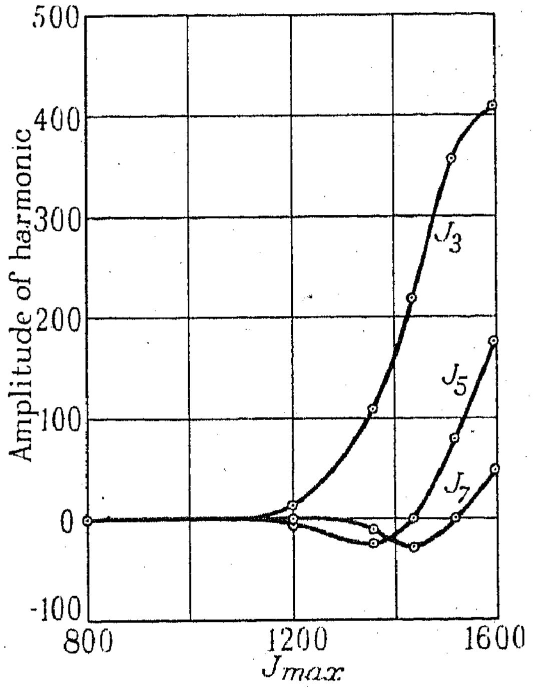


Fig. 5.—Magnitude of harmonics occurring in magnetization during rotation of disc.

It will be clear that, in the case of Sample 1, up to about J_{max} = 1 000 or, say, $(B - H)_{max}$ = 13 000 gauss, the only torque required to rotate the discs is that due to the hysteresis loss, since the harmonics are all substantially zero. At higher inductions there will be an additional alternating torque as given above. It is desired to keep this torque as low as possible, and the greater the number of discs employed the lower it will be. The main limitation to the number of discs is set by the size of the magnet required to maintain a uniform field over the whole of the sample. Since the third harmonic is much greater than the fifth and seventh, as shown in Fig. 5, it will be clear that there is a considerable advantage in using three discs rather than two. There was a further advantage in using three discs rather than two, since that number had been used previously* for rotational hysteresis-loss determination, thus enabling a direct comparison of alternating and rotational hysteresis loss to be made on identically the same samples. The three discs could also be conveniently accommodated in a large electromagnet which was available for the work.

---

* F. Brailsford: *Journal I.E.E.*, 1938, vol. 83.

Using three discs there will thus be a (sin 6α) term, in addition to that due to hysteresis, in the torque acting on the discs during rotation as given by equation (6). The calculated amplitude of this component is shown in Fig. 6. The observed values for Sample 1 are shown by the dotted curve and are in fair agreement with the values calculated by the above theoretical method.

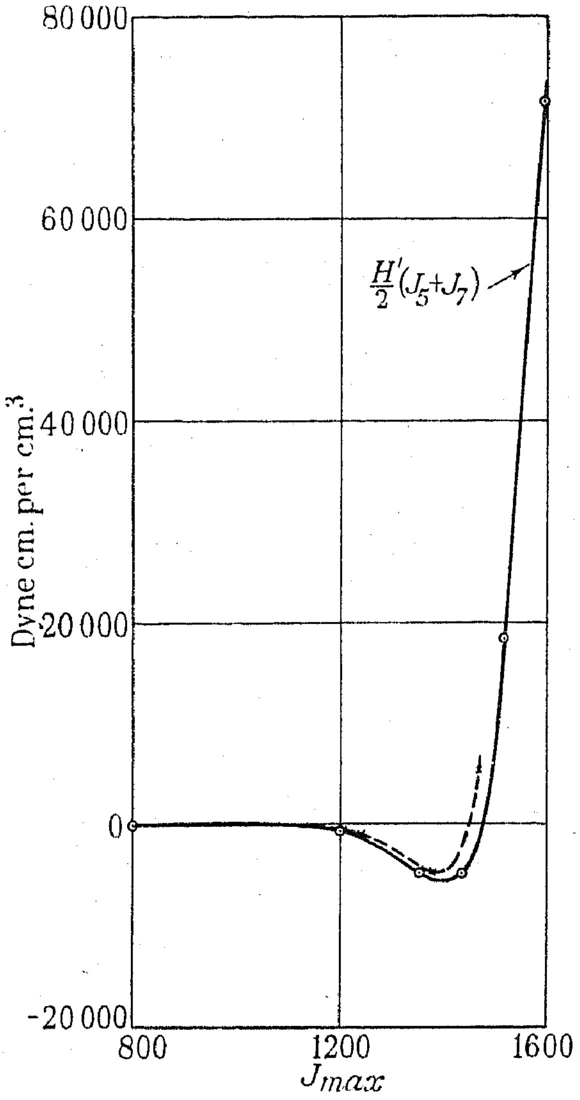


Fig. 6.—Calculated amplitude of (sin 6α) component in torque curve for three discs of Sample 1. (The dotted curve shows observed values.)

Using the observed values of hysteresis loss found experimentally the ratio between the amplitude of the (sin 6α) component in the torque and the average value due to hysteresis loss has been plotted in Fig. 7. It is seen that the ratio is substantially zero up to $J_{max} = 1\,000$ and does not exceed about 4 up to $J_{max} = 1\,470$ or $(B - H)_{max} = 18\,400$ gauss. At that particular intensity of magnetization $J_5 = -J_7$, and the (sin 6α) term disappears, but above this there is a very rapid increase in the ratio. This rapid increase makes 18 500 to 19 000 gauss, in the case of Sample 1, the upper limit of the induction at which one can expect accuracy in the measurement of hysteresis loss by the present method.

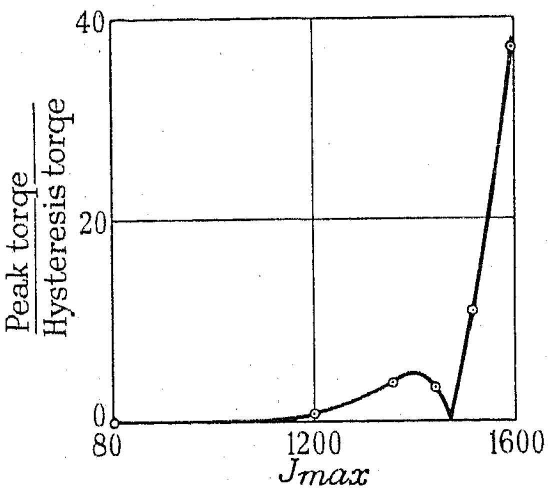


Fig. 7.—Ratio between amplitude of (sin 6α) component of torque, and torque due to hysteresis loss, for Sample 1.

TEST SAMPLES

Particulars of the materials investigated are given in Table 1. Each sample consisted of three discs, of which the silicon content, dimensions, and observed demagnetizing factors N are also given in the Table. The discs are the same as those previously investigated in connection with rotational hysteresis loss, and the complete chemical analyses and other details will be found in the previous paper.

APPARATUS AND PROCEDURE

The three discs were mounted vertically above one another, as shown in Fig. 8, on a thin piece of brass hexagonal rod. This had flats filed on it so that the discs were parallel to the rod in planes relatively displaced at 0°, 60°, and 120°, and with a diameter of the disc in each case coincident with the centre line of the rod. This assembly was then suspended on a phosphor-bronze torsion wire and, below a maximum induction of about 8 000 gauss, was allowed to hang freely in the applied field. At higher inductions it was found convenient to make use of journal jewel bearings to

Table 1

Sample	Designation	Silicon content	Diameter	Mean thickness of single disc	Observed demagnetizing factor (N) of single disc
		per cent	in.	in.	
1	Ordinary electrical dynamo sheet	0·13	1·23	0·0162	0·160
2	Higher-quality dynamo sheet	1·91	1·19	0·0167	0·168
3	Ordinary transformer silicon steel	3·72	1·24	0·0116	0·119
4	Cold-rolled transformer silicon steel	3·13	1·23	0·0133	0·132

prevent lateral movement. The torque was measured from the angle of twist of the torsion wire in the slightly modified torque magnetometer fully described in the previous paper. The torque constant of the suspension was obtained from the periodic time of swing of the suspended system in known manner.

A large electromagnet with an adjustable air-gap was available and was used. The plane, parallel, pole faces of this were approximately 12 in. in diameter and were set at a distance of 5·75 in. apart. A horizontal applied field up to $H' = 450$ gauss could be obtained, working from a battery supply. The applied field-strength H' was measured in relation to the current in the magnetizing coil of the electromagnet, and, in the absence of the specimen, by a search coil and ballistic galvanometer. Tests made indicated that the field was sensibly uniform over the portion of the field in which the specimen was later placed.

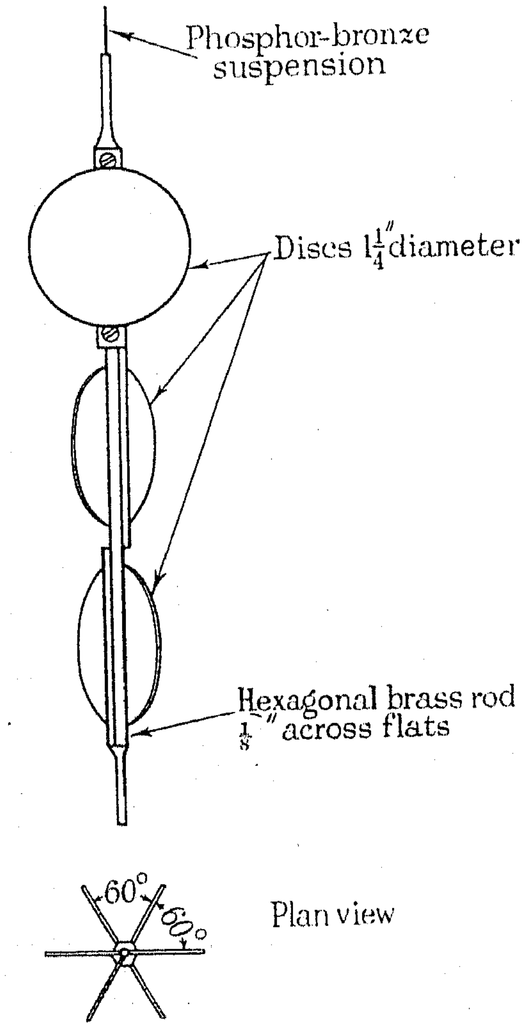

Phosphor-bronze suspension
Discs $1\frac{1}{4}''$ diameter
Hexagonal brass rod $\frac{1}{8}''$ across flats
60°
60°
Plan view

Fig. 8.—Arrangement of disc sample.

The magnetization in the discs was measured ballistically with a search coil consisting of 20 turns of 0·007 in. diameter enamel-covered copper wire, close wound round the disc parallel to any desired diameter. The method of determining the demagnetizing factor N and the effective field H, and of making the necessary corrections, has been described in the previous paper.

The three discs were first set up in the applied field with the rolling direction of each disc in the horizontal plane containing H'. The discs were then rotated through one or two revolutions in an anti-clockwise direction before the first torque measurements were made. The torque necessary just to move the discs in the anti-clockwise direction was then measured, over one revolution, for a series of positions of the discs in the applied field. This procedure was then repeated for the clockwise direction. If these torques are now plotted against the angle of rotation (α), then the area between the curves represents twice the alternating hysteresis loss for the three discs. The alternating hysteresis loss was thus determined for the rolling direction of the material. By repeating the above procedure when the rolling direction of the discs was inclined at $22\frac{1}{2}$°, 45°, $67\frac{1}{2}$°, and 90° respectively to the horizontal the loss was also measured for four other directions in the material relative to the direction of rolling. In the case of Sample 4 (the cold-rolled material), however, the directions chosen were, for reasons which will be apparent later, at 0°, 30°, 54·7°, and 90° to the rolling direction.

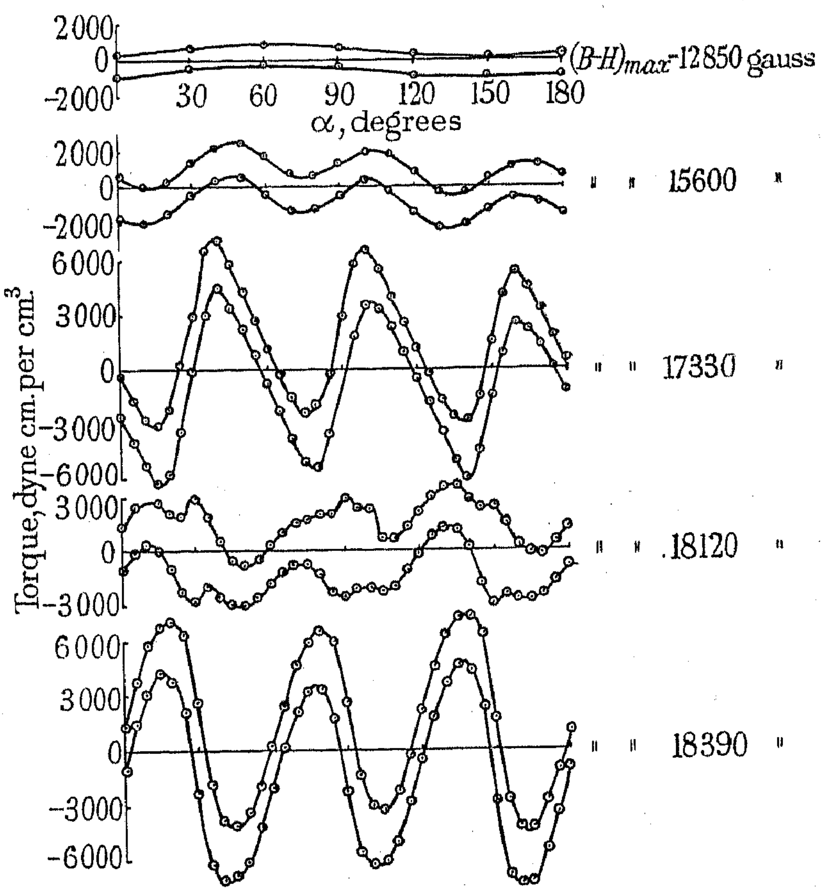


Fig. 9.—Observed torque curves for Sample 1, showing torque per cm.^{3} plotted against angle of rotation (α) of disc, all drawn to same scale.

The upper curve in each case is for clockwise rotation and the lower curve for anti-clockwise rotation of the specimen.

It is considered that the relative accuracy for both flux and loss measurements was about 1 %.

EXPERIMENTAL RESULTS

Typical torque curves for Sample 1 are shown in Fig. 9. At $(B-H)_{max} = 12\,850$ gauss, the ($\sin 6\alpha$) component is seen to be absent. There is, however, a ($\sin 2\alpha$) component in these curves due to small differences in the three discs and slight inaccuracy in their relative alignment. The ($\sin 6\alpha$) component is appreciable at $(B-H)_{max} = 15\,600$ gauss and still greater at $(B-H)_{max} = 17\,330$ gauss. At $(B-H)_{max} = 18\,120$ gauss this component is seen to be again small. This is due to the fact that $(J_5 + J_7)$ is zero near this induction (see Figs. 5 and 6). At $(B-H)_{max} = 18\,390$

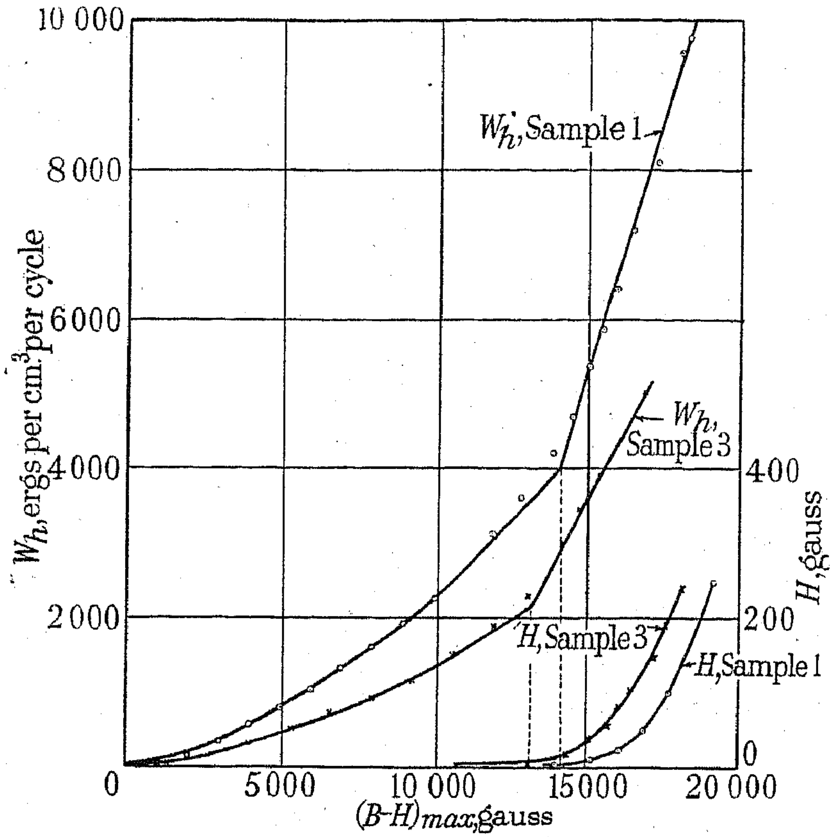


Fig. 10.—Alternating hysteresis and magnetization curves along rolling direction, for Samples 1 and 3.

Equations of full lines are:—

Sample 1. Lower portion, $W_h = 0{\cdot}000914\,B_{max}^{1{\cdot}6}$

Upper portion, $W_h = 1{\cdot}385[(B - H)_{max} - 11\,260]$

Sample 3. Lower portion, $W_h = 0{\cdot}000342\,B_{max}^{1{\cdot}65}$

Upper portion, $W_h = 0{\cdot}774[(B - H)_{max} - 10\,370]$

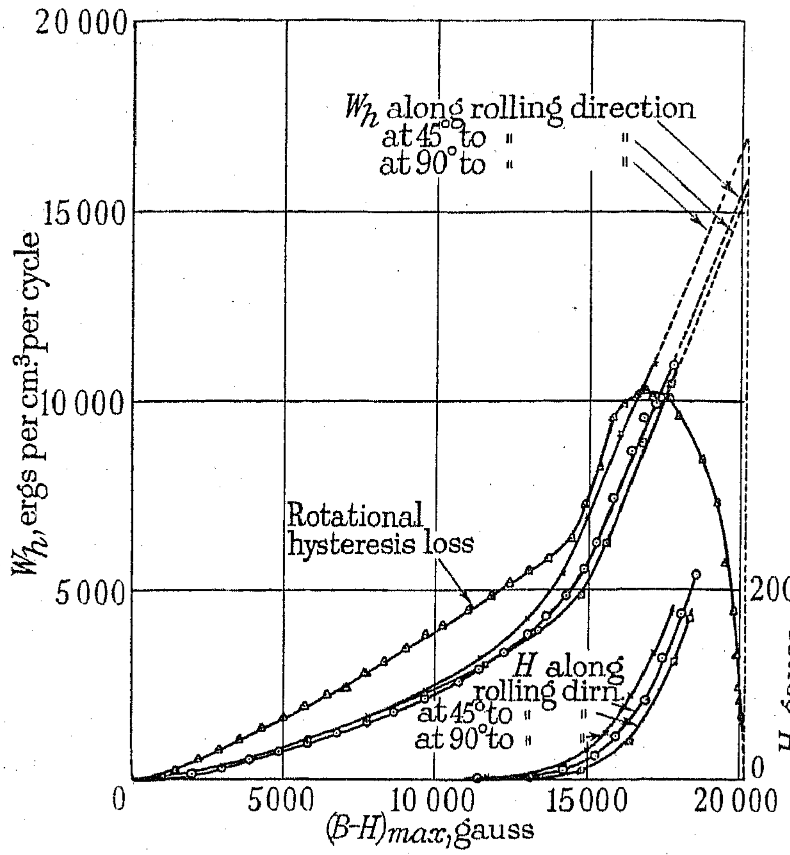


Fig. 12.—Sample 2: comparison of values of alternating hysteresis loss in different directions in the sheet with the corresponding magnetization curves and with the rotational hysteresis loss.

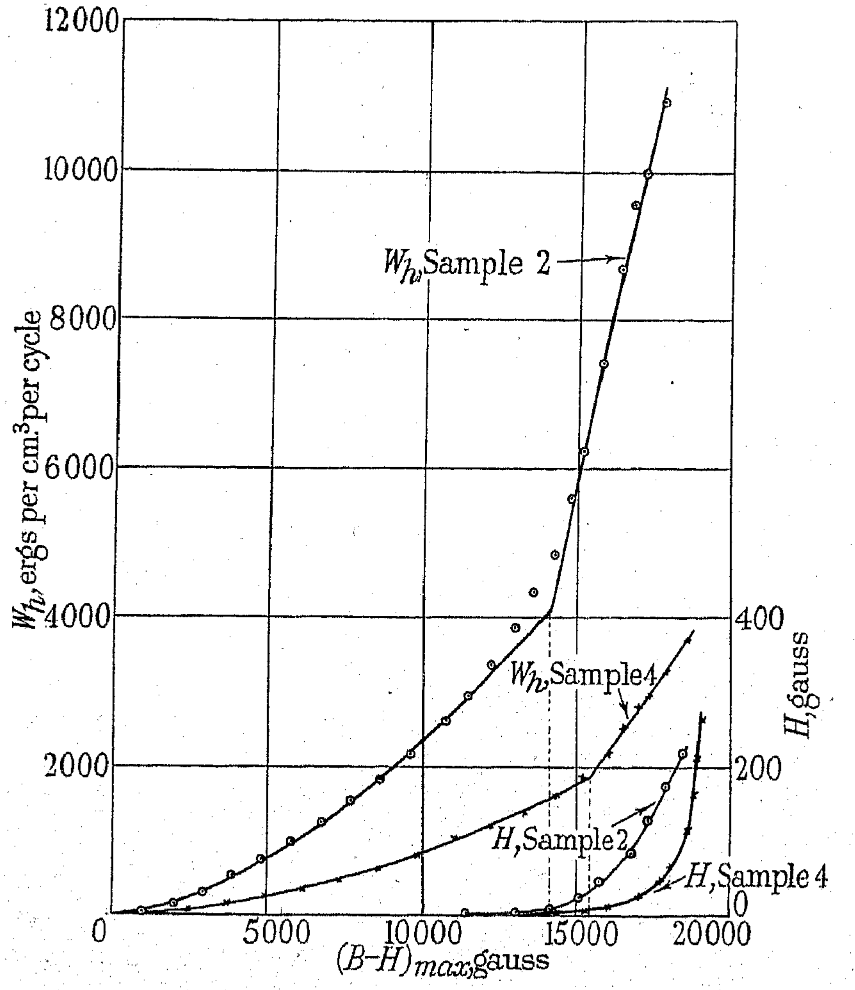


Fig. 11.—Alternating hysteresis and magnetization curve along rolling direction, for Samples 2 and 4.

Equations of full lines are:—

Sample 2. Lower portion, $W_h = 0{\cdot}000586\,B_{max}^{1{\cdot}65}$

Upper portion, $W_h = 1{\cdot}958[B - H)_{max} - 12\,050]$

Sample 4. Lower portion, $W_h = 0{\cdot}000086\,B_{max}^{1{\cdot}8}$

Upper portion, $W_h = 0{\cdot}591[(B - H)_{max} - 12\,370]$

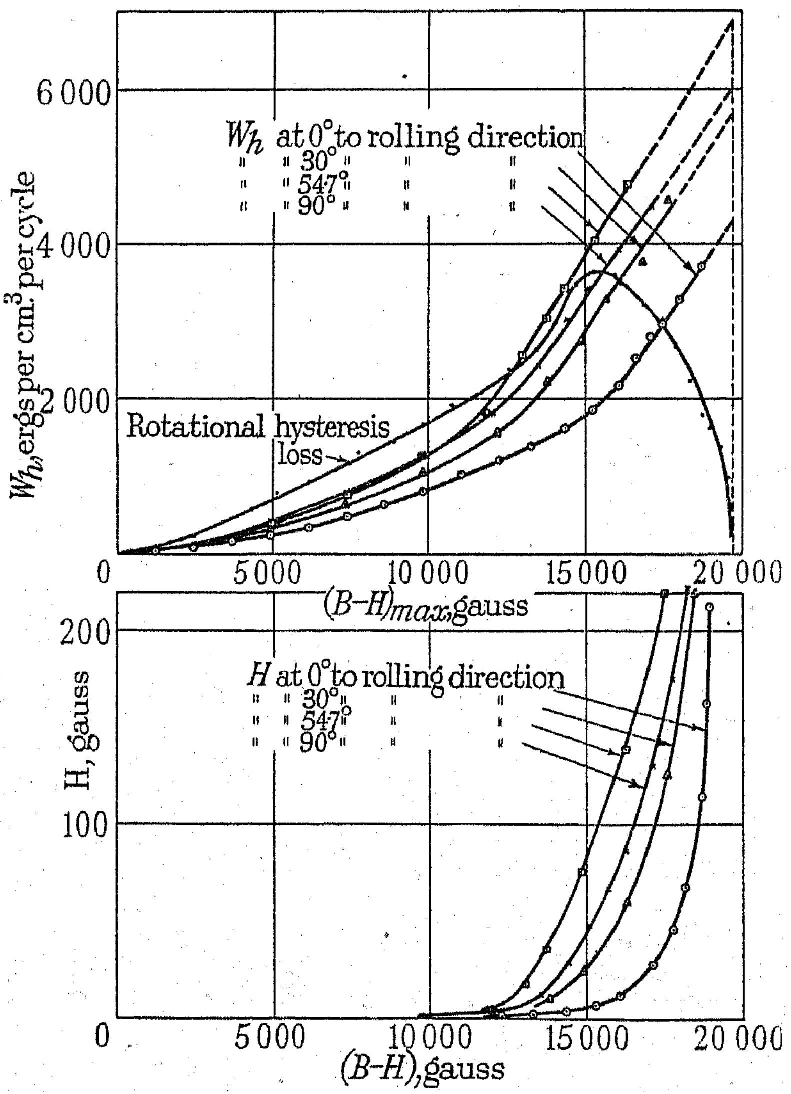


Fig. 13.—Sample 4: comparison of values of alternating hysteresis loss in different directions in the sheet with the corresponding magnetization curves and with the rotational hysteresis loss.

gauss the (sin 6α) component is again large but in opposition to that occurring at lower inductions, which is consistent with $(I_5 + I_7)$ having changed sign [see equation (6)]. These results are therefore in agreement with the theoretical analysis already developed.

The observed values of alternating hysteresis loss in the direction of rolling are given for the four materials in Figs. 10 and 11. It will be seen that in each case the observations can be fitted fairly closely by:—

(*a*) on the lower portion, the Steinmetz law $W_h = aB^n_{max}$.

(*b*) on the upper portion, a straight-line law of the form $W_h = b\left[(B - H)_{max} - c\right]$. Expressing W_h in ergs per cm³ per cycle and B_{max} and $(B - H)_{max}$ in gauss, the values of the constants a, b, c, and n, giving closest agreement with the observed values are shown in Table 2.

The corresponding magnetization curves are plotted in Figs. 10 and 11. It will be observed that the change in the law relating loss and magnetization occurs near the " knee " of the magnetization curve, where, according to the domain theory, the mechanism of the magnetization process also changes.

Table 2

Sample	a	n	b	c
1	0·000914	1·6	1·385	11 260
2	0·000586	1·65	1·958	12 050
3	0·000342	1·65	0·774	10 370
4	0·000086	1·80	0·591	12 370

The loss and magnetization curves for three directions in the sheet are given in Fig. 12 for Sample 2, and the rotational hysteresis loss, obtained in the previous investigation on the same discs, is also shown for comparison. These results are typical of those for Samples 1 and 3 also. The general correspondence between the loss curves and the magnetization curves for the three directions in the sheet may be noticed. This correspondence is, however, seen with greater clearness from the results obtained on Sample 4 and shown in Fig. 13.

More complete results to show the variation of alternating hysteresis loss with direction in the sheet are given for the four materials in Fig. 14. The way in which the loss varies with the direction in the sheet at $B_{max} =$ 13 000 gauss is shown in Fig. 15. The ordinates give the percentage increase or decrease in loss as compared with its value in the rolling direction.

It will be seen that the directional effects are of a different order of magnitude in the case of Sample 4, the cold-rolled silicon steel, from those for Samples 1, 2, and 3, which are normal, hot-rolled materials. The remarkable directional properties of Sample 4 are undoubtedly due to a high degree of preferred orientation of the crystals making up the polycrystalline sheet, the individual crystals being themselves magnetically anisotropic. A magnetic method of determining the approximate crystal arrangement in the sheet, where this arrangement is of a simple character, has been suggested* and, as shown in the previous paper, has been applied to Sample 4. It was concluded that approximately two-thirds of the material had the crystals lined up so that (*a*) a cube-edge crystal direction was parallel to the rolling direction; (*b*) a cube-face diagonal lay in the plane of the sheet normal to the rolling direction, resulting in (*c*) the long diagonal direction of the cube being at 54·7° to the direction of rolling.

This particular crystal orientation should lead, in consequence of the magnetic properties of single crystals of iron† or of silicon iron,‡ to the magnetization curve being best for the rolling direction, worst at 54·7°, and having an intermediate position at 90° to the rolling direction. It was for this reason that these particular directions in the sheet were chosen for investigation in the case of Sample 4. It will be seen from Fig. 13 that the expected relationship between the magnetization curves has, indeed, been found. It is further seen that the loss curves in the different directions are in a similar relationship. The observed results are therefore consistent with the idea that, in a single crystal of iron or silicon iron, the hysteresis loss would be a minimum for alternating magnetization in a cube-edge direction,

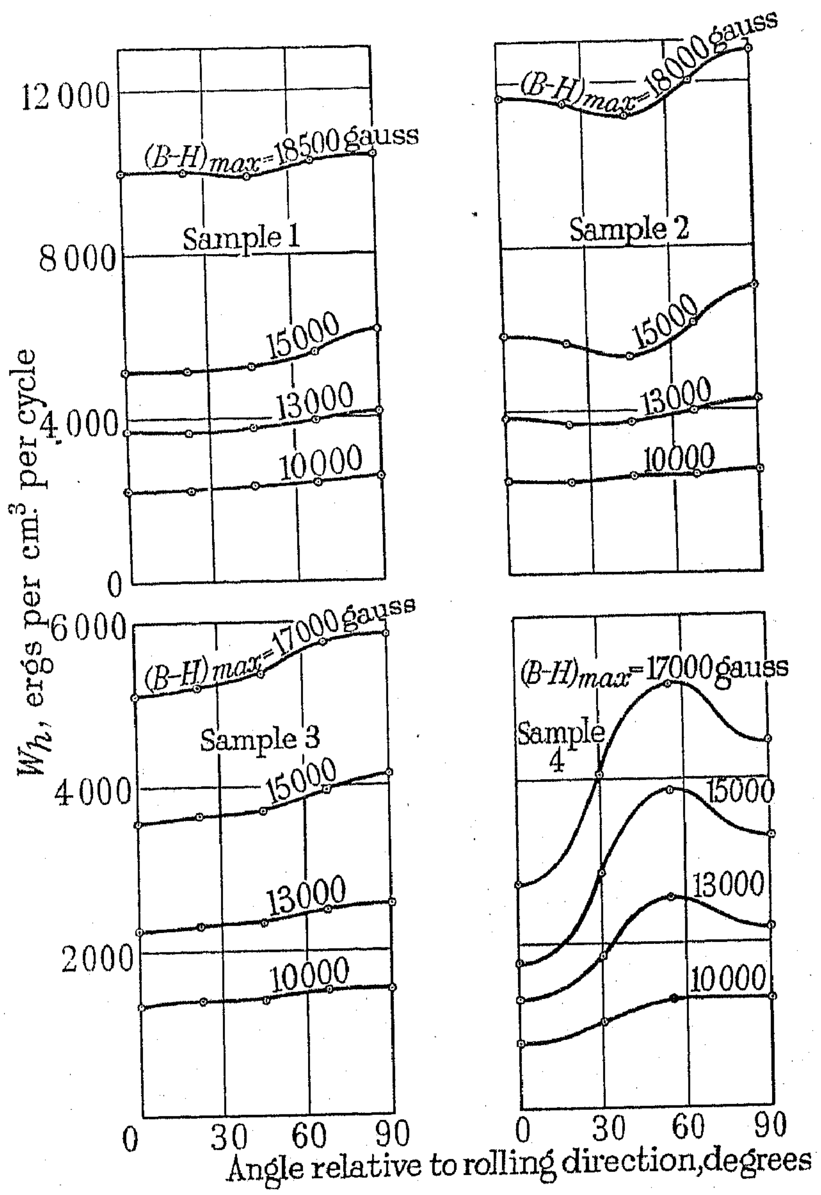


Fig. 14.—Variation of alternating hysteresis loss with direction in the sheet.

---

[*] N. S. Akulov and N. Bruchatov: *Annalen der Physik*, 1932, vol. 15, p. 741.

[†] K. Honda and S. Kaya: *Scientific Reports of Tohoku University*, 1926, vol. 15, p. 721.

[‡] H. J. Williams: *Physical Review*, 1937, vol. 52, p. 747.

where H is also a minimum and that the loss would be a maximum in the direction of the long diagonal, where H is also a maximum.

If it is assumed that the observed loss curves can be safely extrapolated to $(B - H)$ at saturation, as in Figs. 12 and 13, then we have the complete loss curve, and the loss can be replotted against B_{max}, provided the magnetization curve is known, to any value of B_{max} desired. It will be clear that on this basis the alternating hysteresis loss cannot exceed its value at the saturation value of magnetization, and the loss curve plotted against the induction B_{max} must bend over at high flux densities, as shown in Fig. 16. In this Figure the loss is shown for the four materials in the rolling direction.

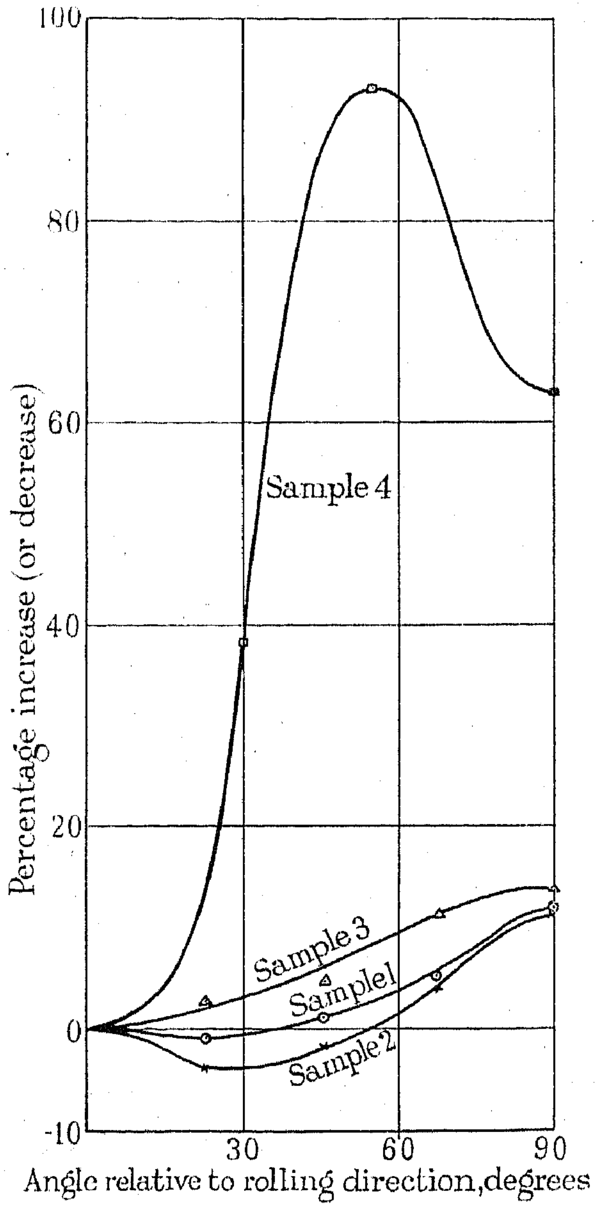


Fig. 15.—Variation of alternating hysteresis loss with direction in the sheet.

The ordinates give the percentage increase in the loss over its value in the rolling direction at $B_{max} = 13\ 000$ gauss.

Finally, the ratio between rotational and alternating hysteresis is shown, for the four samples, in Fig. 17. The mean value of alternating hysteresis loss for all directions in the sheet has been taken in obtaining this ratio. These observed ratios are seen to fall fairly close to the drawn curve for all the four materials.

DISCUSSION

In the previous investigation on rotational hysteresis losses a more rapid rise in loss with increase of the

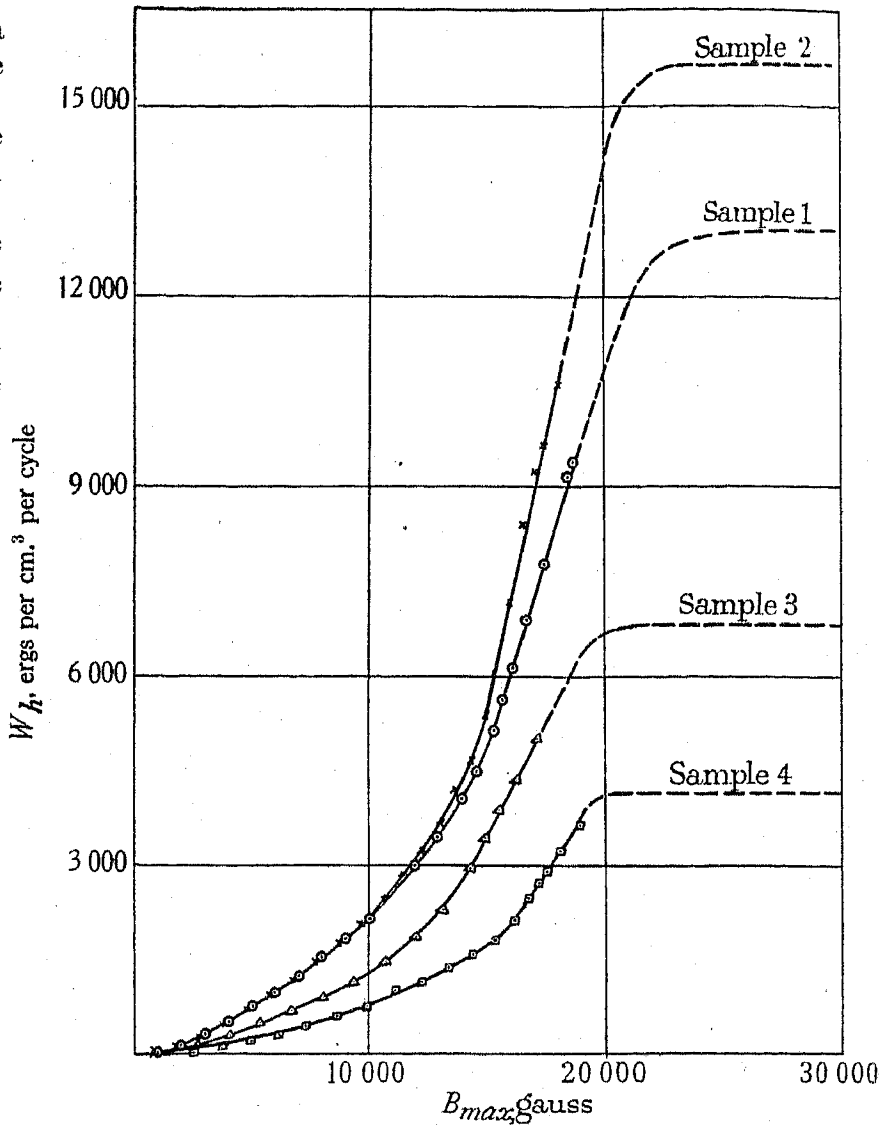


Fig. 16.—Alternating hysteresis loss plotted against the induction B_{max}, showing probable shape of curves at high inductions.

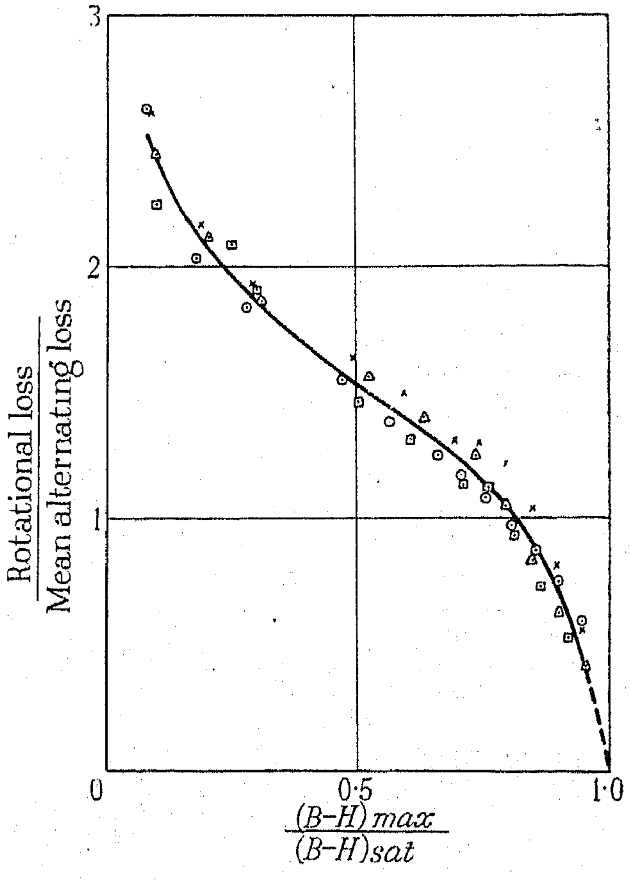


Fig. 17.—Relation between rotational hysteresis loss and mean alternating hysteresis loss for four materials.

⊙ Sample 1.
× Sample 2.
△ Sample 3.
⊡ Sample 4.

magnetization was observed to occur at the knee of the magnetization curve, where a rapid increase of H with increase of magnetization also occurred. The present results for alternating magnetization show the same phenomenon, supporting the view that the hysteresis loss is a function not only of J but of H also. This is now manifested, in addition, in another way. It is seen in all cases, and with particular clearness in Fig. 13 for Sample 4, that, where the alternating magnetization is applied in different direction in the sheet, the loss curves and magnetization curves fall in the same order, i.e. a high loss is associated with a poor magnetization curve, and vice versa.

An explanation of the connection between hysteresis loss and the effective field has been given in the previous paper and, in view of the present additional evidence, may be repeated for completeness.

Hysteresis loss is produced during magnetization at each Barkhausen discontinuity;[*] that is, according to the domain theory,[†] for every sudden change of direction of the spontaneous magnetization in small volumes of the material known as the "domains." With increasing H the potential energy of any one of these regions will change and may reach an unstable value. A sudden change in direction of the magnetization in the region will then occur, involving a reduction of the potential energy from a higher to a lower value. This sudden change is, in part, irreversible, and hence a portion of the change of energy is dissipated as hysteresis loss. Clearly the higher the value of H at the instant of the change the higher the change in potential energy, and so the higher the hysteresis loss for a given volume of domain or increment in the magnetization. Thus, in comparing two directions in a sample of sheet material, the direction having the poorer magnetization curve will also have the higher alternating hysteresis loss.

According to the simple theory, the Barkhausen discontinuities all occur below the "knee" of the magnetization curve, the mechanism of magnetization being of a different character above this point. But in a practical case they also occur[‡] above the knee. In electrical sheets, which are well-annealed materials with comparatively low internal strains, H is small below the knee and the rate of increase of hysteresis loss with increase of magnetization will be comparatively low. Above the knee H rapidly becomes of a different order of magnitude, and, although the magnetization does not now increase entirely by Barkhausen increments but mainly by smooth rotation[§] of the spontaneous magnetization in the domains, it is reasonable to expect a change in the law relating loss and magnetization to occur at this point. The observed results (Figs. 10 to 13) show, in fact, that in the neighbourhood of the knee there is, in every case, a fairly sudden change in the law relating loss and magnetization.

CONCLUSION

The preceding work may be summarized as follows:—

(*a*) The method described enables alternating hysteresis loss to be measured directly with comparatively simple apparatus, no eddy-current losses being involved in the measurements. Measurements in any direction in the sheet may be made on the same sample, and only a small quantity of material is required.

(*b*) A change in the law relating alternating hysteresis loss and magnetization occurs in the neighbourhood of the knee of the magnetization curve, where, according to theory, the mechanism of the magnetization process also changes. Below the knee the Steinmetz law is operative, but above the knee a straight-line law holds.

(*c*) Alternating hysteresis loss varies not only with the magnetization but also with the value of the corresponding field strength. This is shown up by (i) the connection between the knee of the magnetization curve and a similar discontinuity in the loss curve for a given direction in the sheet; (ii) the correspondence of the magnetization curves in different directions in a particular material with the loss curves for the same directions.

(*d*) For the ordinary hot-rolled sheets—Samples 1, 2, and 3—the direction of maximum loss is at 90° to the rolling direction, being from 11 % to 14 % greater than along the rolling direction at $B_{max} = 13\,000$ gauss. In some cases minimum loss occurs at about 30° to the rolling direction.

(*e*) The variation of loss with direction in the sheet is enormously greater in the case of Sample 4, the cold-rolled silicon steel, than for the hot-rolled materials. In this case the loss is a maximum at about 54·7° to the rolling direction, a minimum along the rolling direction, and has an intermediate value at 90° to the rolling direction. At $B_{max} = 13\,000$ gauss, the alternating hysteresis loss is 63 % greater at 90° to the rolling direction than it is along that direction, and 93 % greater at 54·7°.

(*f*) It is inferred from the results obtained on the cold-rolled material that, in a single crystal of the material, having randomly-directed internal strains, alternating hysteresis loss would be a minimum along the cube-edge crystal direction, a maximum along the long diagonal of the cube, and have an intermediate value in the direction of a cube-face diagonal.

(*g*) If it is assumed that the straight-line law relating loss and magnetization is maintained up to saturation, then the loss may be deduced from the observations made up to any desired value of the induction B_{max}.

(*h*) The ratio of rotational to alternating hysteresis loss is found to be approximately the same for all the four materials examined. It should therefore be possible to deduce the rotational hysteresis loss for any material of this type, knowing its alternating hysteresis loss, by making use of the ratios given in Fig. 17.

ACKNOWLEDGMENTS

The author wishes to record his indebtedness to Mr. H. T. W. Wilding, for assistance with the flux measurements; to Dr. C. Dannatt, in whose laboratory the work was carried out; to Mr. B. G. Churcher, for his encouragement throughout the investigation; to Dr. A. P. M. Fleming, C.B.E., Director and Manager of the Metropolitan-Vickers Electrical Company's Research and Education Departments; and to the Company, for permission to publish the paper.

---

[*] H. Barkhausen: *Physikalische Zeitschrift*, 1919, vol. 20, p. 401.

[†] E. C. Stoner: "Magnetism and Matter" (London, 1934), p. 390.

[‡] R. M. Bozorth and J. F. Dillinger: *Physical Review*, 1930, vol. 35, p. 733.

[§] N. S. Akulov: *Zeitschrift für Physik*, 1931, vol. 67, p. 794.

A NOTE ON STANDARD CALIBRATIONS FOR SPHERE-GAPS[*]

By S. WHITEHEAD, M.A., Ph.D., Associate Member.[†]

(*Paper first received 5th August, and in final form 30th November, 1938.*)

SUMMARY

The general principles which underlie the recent revision of the I.E.C. sphere-gap calibrations are given. An outline of the theory of sparkover between spheres is indicated, leading to the definition and evaluation of the "asymmetry" of a sphere-gap and to the determination of the effect of earthing one sphere, the polarity effect, and the influence of neighbouring bodies. The correction for air density is also considered.

(1) INTRODUCTION

At the Plenary Meeting of the I.E.C.[‡] at Torquay (June, 1938) a revision of the I.E.C. " Rules for the Use of Sphere-Gaps " (Publication 52) was approved for issue to the national committees under the Six Months' Rule, with the reasonable prospect that the national standards of most countries would be altered to conform therewith. This revision is comprehensive and is based upon a comparison of a large number of recent investigations carried out in several countries, particularly Germany, Great Britain, and the U.S.A. It may therefore be of interest to record some of the principles which are inherent in the revised standards, particularly those which are either new or are rarely mentioned in the literature of the subject. At the same time the following notes bear on some of the points raised at the discussion on this subject before The Institution in January, 1938.[§]

(2) DERIVATION OF MEAN CURVES

The history of the comparisons made in different countries of groups of experimental results, and the subsequent derivation of the final values accepted by the I.E.C., are described in some detail by Weicker and Hörcher.[||] It will therefore suffice here to indicate the main experimental sources and the guiding principles employed in selecting the final curves. The earlier work (prior to, say, 1934 or 1935) up to 400 kV was in general agreement with the existing I.E.C. standards (I.E.C. Publication 52). The work in the U.S.A. of Bellaschi and McAuley[¶] and also of Meador[**] had been incorporated in the draft American I.E.E. Standards for sphere-gap measurements and had previously been adopted by the I.E.C. as regards spheres of 50 cm. and above; a distinction was made in the new review between the values within the range actually obtained experimentally and the values extrapolated therefrom. The results of the recent investigations of the following workers were individually considered: Elsner,[‡] Dattan,[§] Jacobi,[||] Hueter,[¶] Binder and Hörcher,[**] P.T.R. Laboratory Report (Germany), Edwards and Smee,[††] Davis and Bowdler (Great Britain).[‡‡] The results obtained by earlier investigators were, of course, also referred to, and recent American work was taken into consideration.[§§]

The great majority of these results at power frequencies could be comprised within limits differing by 10 % and, in fact, more frequently within 5 % limits. It was then agreed that the final values should be as consistent as possible as between different sizes of spheres, and that the voltage/spacing curves should be smooth. The consistency between different sphere-sizes was determined by the relation:—

$$\text{Sparkover gradient at surface} = \frac{V}{s} \times (N \text{ or } N_1) = \epsilon$$

$$= \epsilon_0 + \frac{\phi(s/d)}{\sqrt{d}} \text{ [see Section (3)] } \quad . \quad . \quad . \quad (1)$$

where N = Russell's factor for symmetrical voltages, N_1 = Russell's factor for one sphere earthed, s = spacing, d = diameter, and V = p.d. between the spheres.

The second term may be written $\psi(s/d)/\sqrt{s}$, and when d becomes very large the field becomes uniform, $\psi(s/d)$ tending to a limit so that

$$\epsilon = \epsilon_0 + \frac{c}{\sqrt{s}} \quad . \quad . \quad . \quad . \quad . \quad (1.1)$$

This is the Toepler–Stephenson formula for a uniform field. Various values have been given for ϵ_0 in tests on uniform fields, but a value (communicated by W. M. Thornton)[||||] of 24·75 kV (crest) per cm. was adopted. The value of ϵ_0 does not, however, require to be known to a high accuracy for the present purpose. As has already been pointed out by the present author,[¶¶] owing to the effect known as the Toepler discontinuity,[***] the results for a given value of s/d lie actually on two curves instead of one as required by (1), these two curves intersecting at the point where s and d agree with the Toepler *knickstelle*[†††] relation. This conclusion is only very roughly true. However, as it had been decided that the final curves should be smooth and that this discontinuity should be neglected, the final result, shown in Figs. 1 and 2, departed to some extent from (1) but agreed with the extrapolated value of ϵ_0 and also with the form of (1) when a limited range was considered. It was indeed found that to obey these conditions, and at the same time to keep fairly near the mean of the experimental results for each size of sphere, determined the choice to within about 1 % or less, and the final values were obtained by ensuring consistency between earthed and insulated spheres.

---

[*] The Papers Committee invite written communications, for consideration with a view to publication on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of The Institution not later than one month after publication of the paper to which they relate.

[†] British Electrical and Allied Industries Research Association.

[‡] The author is Chairman of the Sub-Committee on Sphere-gap Calibrations, International Electrotechnical Commission.

[§] R. Davis and G. W. Bowdler: *Journal I.E.E.*, 1938, vol. 82, p. 645; F. S. Edwards and J. F. Smee: *ibid.*, 1938, vol. 82, p. 655.

[||] *Elektrotechnische Zeitschrift*, 1938, vol. 59, pp. 1029 and 1064.

[¶] *Electric Journal*, 1934, vol. 31, p. 228.

[**] *Electrical Engineering*, 1934, vol. 53, pp. 942 and 1652.

[‡] *Elektrotechnische Zeitschrift*, 1935, vol. 56, p. 1405.

[§] *Ibid.*, 1936, vol. 57, pp. 377 and 412; *Archiv für Elektrotechnik*, 1937, vol. 31, p. 342.

[||] *Zeitschrift für technische Physik*, 1936, vol. 5, p. 159.

[¶] *Elektrotechnische Zeitschrift*, 1936, vol. 57, p. 621.

[**] *Ibid.*, 1938, vol. 59, p. 161.

[††] *Loc. cit.*

[‡‡] *Loc. cit.*

[§§] R. W. Sorensen and S. Ramo: *Electrical Engineering*, 1936, vol. 55, p. 444; C. S. Sprague and G. Gold, *ibid.*, 1937, vol. 56, p. 594.

[||||] Thornton also gave 5·95 for c.

[¶¶] *Journal I.E.E.*, 1938, vol. 82, p. 669.

[***] *Archiv für Elektrotechnik*, 1938, vol. 7, p. 485, and earlier references given therein.

[†††] *Ibid.*

In estimating where an experimental mean should probably lie, account was taken of experimental dispersion, conditions of installation, mode of calibration, etc., but no general rules could be laid down.

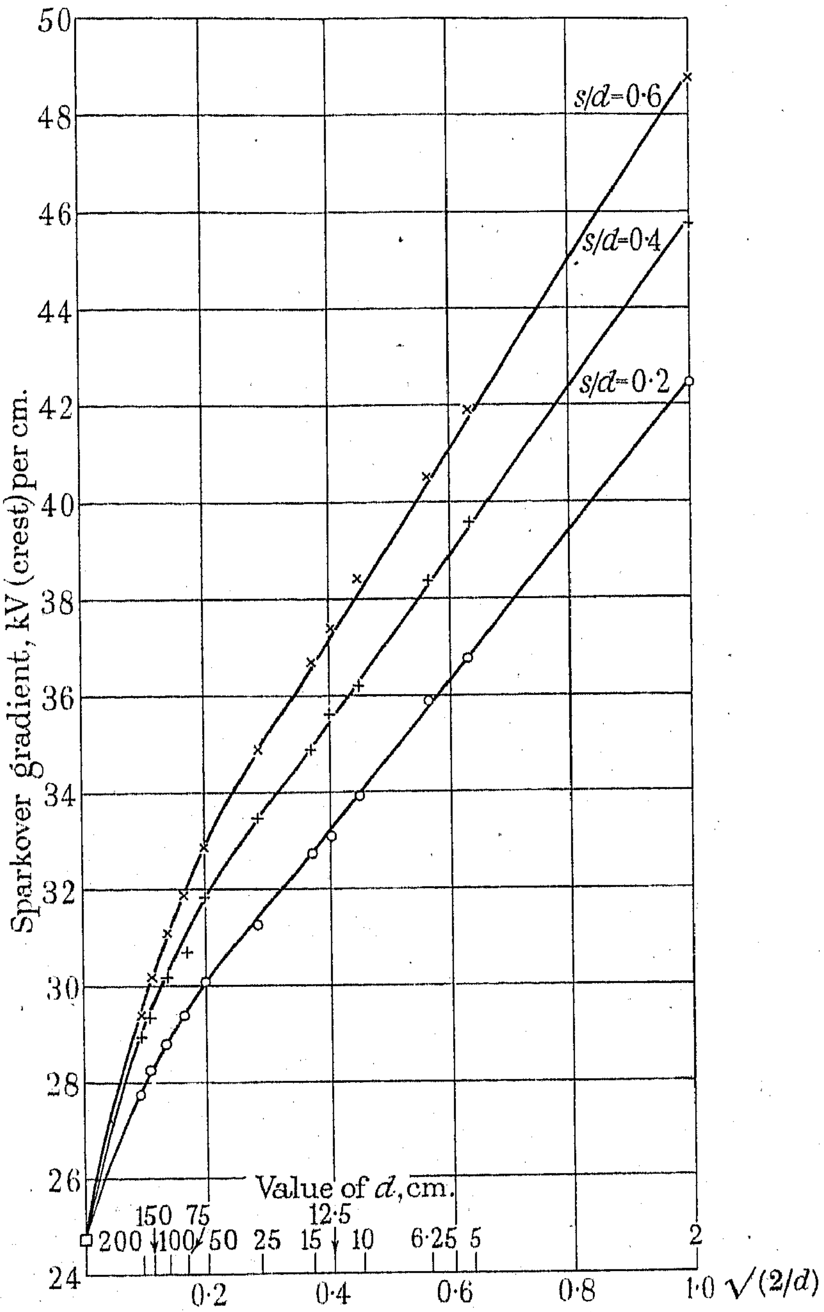


Fig. 1.—One sphere earthed.

The final values approved for submission to the National Committees of the I.E.C. are given in Tables 1, 2, and 3.

(3) EARTHED AND INSULATED SPHERES: INFLUENCE OF EXTERNAL BODIES: POLARITY

Russell[*] gave the formal solution for the electrostatic field between two equal spheres which leads to the following expression for the field ϵ at the vertex or sparking point of Sphere 1:—

$$\epsilon = \frac{v_1 - v_2}{s}N + \frac{v_1 + v_2}{s}(N_1 - N) \quad . \quad . \quad (2)$$

where v_1 and v_2 are the potentials of Spheres 1 and 2 respectively, and N and N_1 are known tabulated functions[*] of s/d. This result is obtained on the assumption that the plane at infinity is at zero potential, i.e. the field is everywhere radial at infinity. This is difficult of physical interpretation, since the disposition of the actual circuit determines the potential to be assumed at infinity. Now, if k_{11}, k_{22}, k_{12} are the self and mutual influence coefficients of the spheres,

$$\frac{v_1 + v_2}{v_1 - v_2} = \frac{k_{22} - k_{11}}{k_{11} + k_{22} + k_{12}} = \lambda \quad . \quad . \quad (2.1)$$

λ expresses the capacitative asymmetry of the two poles of the circuit, including any conductors connected thereto, with respect to the ultimate surroundings. If, further, Sphere 1 is taken to be the high-voltage sphere, i.e. if the initiation of sparkover is determined by the field conditions near this sphere, then, if the lower sphere is earthed, k_{22} probably exceeds k_{11} since Sphere 2 is nearer earth, and λ is positive; while if the upper sphere is earthed then Sphere 1 is probably nearer earth, k_{11} probably exceeds k_{22}, and λ is negative. If the circuit is symmetrical, as may be achieved by earthing the mid-point of the high-voltage supply or by supplying similar guard-rings, backing plates, etc., such that k_{12} is greatly

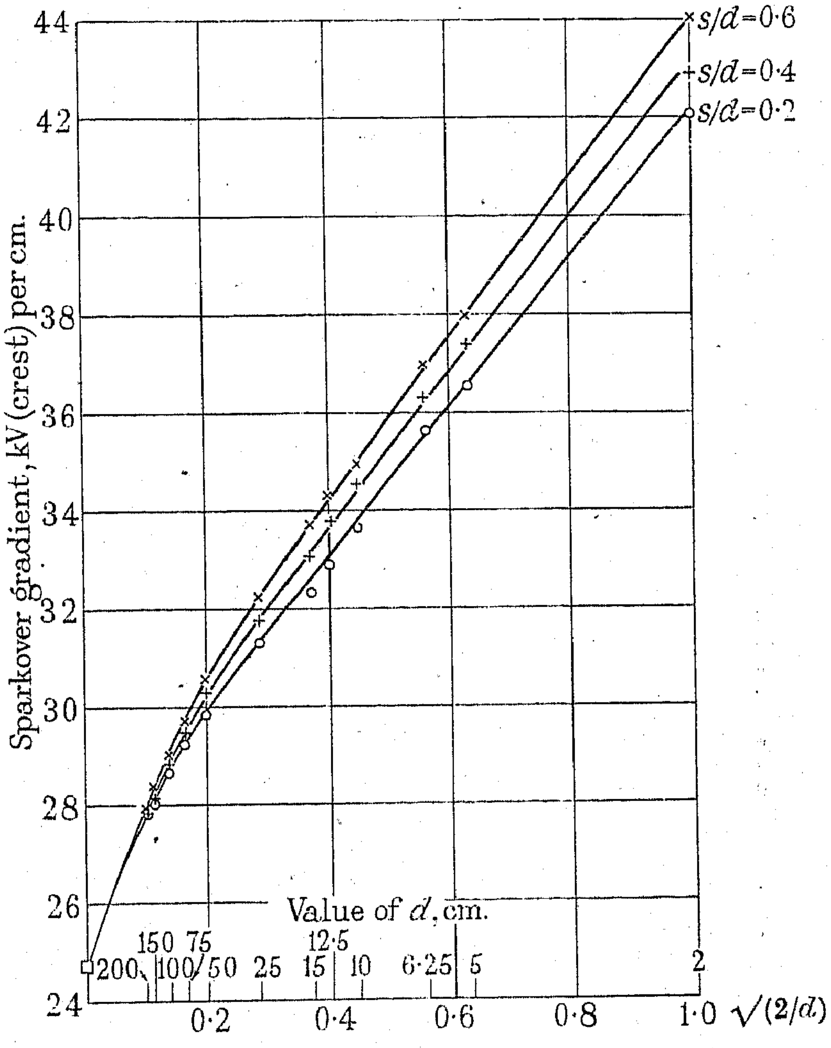


Fig. 2.—Symmetrical voltages.

---

[*] "Alternating Currents," vol. 1, chap. 8.

[*] A. Russell: *loc cit.*; also "Sphere-gap Voltage Measurement Standardization," Report to I.E.C., New York, 1926 (E.R.A. Report Ref. L/T16).

Table 1

SPARKOVER VOLTAGES (IN KILOVOLTS CREST) FOR ONE SPHERE EARTHED AT 20° C., 760 MM. HG PRESSURE, FOR POWER-FREQUENCY ALTERNATING, NEGATIVE IMPULSE, AND NEGATIVE CONTINUOUS UNIDIRECTIONAL VOLTAGES

Spacing, cm.	Sphere diameter, cm.											
	2	5	6·25	10	12·5	15	25	50	75	100	150	200
0·05	2·4											
0·1	4·4											
0·15	6·3											
0·2	8·2	8·0										
0·3	11·5											
0·4	14·8	14·3	14·2									
0·5	18·0			16·9	16·7	16·5						
0·6	21·0	20·4	20·2									
0·7	23·9											
0·8	26·6	26·3	26·2									
0·9	29·0											
1	31·2	32·0	31·9	31·6	31·5	31·3	31					
1·2	35·1	37·6	37·5									
1·4	38·5	43·0	43·0									
1·5	40·0			45·6	45·6	45·5	45					
1·6	(41·4)	48·1	48·4									
1·8	(44·0)	53·0	53·6									
2	(46·2)	57·4	58·2	59·1	59·2	59·2	59	58	58			
2·2		61·5	63·1									
2·4		65·3	67·4									
2·5		67·2	69·6	72·0	72·0	72·6	72			71		
3		75·4	79·1	84·1	85·2	85·5	86					
3·5		82·4	87·5	95·2	97·2	98·1						
4		(88·4)	94·8	105	109	110	112	112	112			
4·5		(93·5)	101	115	119	122						
5		(98·0)	(107)	123	129	132	137			137	137	137
5·5			(112)	131	138	143						
6			(116)	138	146	152	161	164	164			
6·5				144	154	161						
7				150	162	169	184					
7·5				155	168	177						
8				(160)	174	185	205	214	215			
9				(169)	186	198	225					
10				(177)	(196)	209	243	262	265	266	267	265
11					(204)	219	260					
12					(212)	(229)	275	308	313			
13						(238)	289					
14						(245)	302	352	360			
15						(252)	314			387	388	389
16							325	392	406			
18							345	428	450			
20							(363)	461	492	503	508	510
22							(378)	491	532			
24							(391)	520	570			
25							(396)			611	626	630
26								545	606			
28								570	640			
30								591	670	709	739	745
32								611	702			
34								630	731			
35										797	846	858
36								647	756			
38								(663)	785			
40								(679)	806	876	947	965
45								(710)	858	949	1 040	1 070
50								(738)	904	1 010	1 130	1 180
55									945	1 070	1 210	
60									(983)	1 120	1 280	
65									(1 010)	1 160	1 350	1 360
70									(1 040)	1 210	1 420	1 530
75									(1 060)	1 240	1 470	
80										(1 280)	1 530	1 680
90										(1 330)	1 630	1 810
100										(1 370)	1 710	1 930
110											1 790	2 030
120											(1 850)	2 120
130											(1 900)	2 200
140											(1 950)	2 280
150											(1 980)	2 350
160												(2 410)
180												(2 500)
200												(2 580)

Table 2

SPARKOVER VOLTAGES (IN KILOVOLTS CREST) AT 20° C., 760 MM. HG PRESSURE FOR SYMMETRICAL POWER-FREQUENCY ALTERNATING VOLTAGES

Spacing, cm.	Sphere diameter, cm.											
	2	5	6·25	10	12·5	15	25	50	75	100	150	200
0·05	2·4											
0·1	4·4											
0·15	6·3											
0·2	8·2	8·0										
0·3	11·6											
0·4	14·9	14·3	14·2									
0·5	18·1			16·9	16·7	16·5						
0·6	21·2	20·4	20·2									
0·7	24·1											
0·8	26·9	26·4	26·2									
0·9	29·5											
1	32·0	32·2	32·0	31·6	31·5	31·3	31					
1·2	36·7	37·8	37·6									
1·4	41·2	43·3	43·2									
1·5				45·8	45·7	45·5	45					
1·6	(45·2)	48·5	48·6									
1·8	(48·7)	53·5	53·9									
2	(51·8)	58·3	59·0	59·3	59·4	59·2	59	58	58			
2·2		62·8	63·9									
2·4		67·3	68·6									
2·5		69·4	70·9	72·4	72·6	72·9	72			71		
3		79·3	81·8	84·9	85·4	85·8	86					
3·5		88·3	91·8	96·5	97·7	98·4						
4		(96·4)	101	107	110	111	113	112	112			
4·5		(104)	109	118	121	123						
5		(111)	(117)	128	132	134	138			137	137	137
5·5			(124)	137	142	145						
6			(131)	146	152	155	162	164	164			
6·5				155	161	165						
7				163	170	175	185					
7·5				170	179	185						
8				(177)	187	194	207	214	215			
9				(191)	203	211	228					
10				(203)	(217)	227	248	263	265	266	267	267
11					(229)	242	267					
12					(241)	(256)	286	309	314			
13						(268)	303					
14						(280)	320	353	362			
15						(292)	336			388	389	389
16							352	394	408			
18							381	434	452			
20							(407)	472	495	504	511	511
22							(431)	507	535			
24							(452)	542	576			
25							(463)			613	628	632
26								575	615			
28								607	652			
30								638	689	714	741	747
32								666	725			
34								693	759			
35								718	793	812	848	860
36								(742)	825			
38								(767)	856			
40								(823)	929	902	950	972
45										986	1 050	1 080
50								(874)	997	1 070	1 140	1 180
55									1 060	1 140	1 230	
60									(1 120)	1 210	1 320	1 380
65									(1 170)	1 280	1 410	
70									(1 220)	1 340	1 490	1 560
75									(1 270)	1 400	1 560	
80										(1 460)	1 640	1 730
90										(1 560)	1 780	1 900
100										(1 660)	1 910	2 050
110											2 030	2 190
120											(2 140)	2 330
130											(2 240)	2 460
140											(2 330)	2 580
150											(2 420)	2 690
160												(2 800)
180												(3 000)
200												(3 180)

Table 3

SPARKOVER VOLTAGES (IN KILOVOLTS CREST) FOR ONE SPHERE EARTHED AT 20° C., 760 MM. HG PRESSURE, FOR POSITIVE IMPULSE AND POSITIVE CONTINUOUS UNIDIRECTIONAL VOLTAGES

Spacing, cm.	Sphere diameter, cm.											
	2	5	6·25	10	12·5	15	25	50	75	100	150	200
0·4		14·3	14·2									
0·5				16·9	16·7	16·5						
0·6		20·4	20·2									
0·8		26·3	26·2									
1		32·0	31·9	31·6	31·6	31·3	31					
1·2		37·8	37·6									
1·4		43·3	43·1									
1·5				45·6	45·6	45·5						
1·6		49·0	49·0									
1·8		54·4	54·6									
2		59·4	60·0	59·1	59·2	59·2	59	58	58			
2·2		64·2	65·0									
2·4		68·8	69·7									
2·5		71·0	72·3	72·8	72·5	72·6						
3		81·0	83·4	85·6	85·7	85·6	86					
3·5		90·0	93·4	97·4	98·6	98·7						
4		(97·5)	103	109	111	111	112	112	112			
4·5		(104)	110	120	123	124						
5		(109)	(117)	130	134	136	138			137	137	137
5·5			(123)	139	144	147						
6			(128)	148	154	158	162	164	164			
6·5				156	163	168						
7				163	172	178	187					
7·5				170	180	187						
8				(176)	188	196	210	214	215			
9				(186)	202	212	232					
10				(195)	(214)	226	252	262	265	266	267	265
11					(224)	238	272					
12					(232)	(249)	290	310	313			
13						(260)	306					
14						(269)	321	356	360			
15						(276)	335			388	388	389
16							348	401	407			
18							372	440	452			
20							(393)	478	499	505	509	510
22							(410)	511	541			
24							(424)	543	582			
25							(430)			616	626	
26								572	621			
28								600	659			
30								625	694	719	740	745
32								646	727			
34								669	759			
35										816	850	
36								687	788			
38								(705)	816			
40								(721)	841	900	957	967
45								(756)	899	979	1 060	
50								(785)	949	1 050	1 150	1 180
55									994	1 110	1 240	
60									(1 030)	1 160	1 310	1 380
65									(1 070)	1 210	1 390	
70									(1 100)	1 260	1 460	1 560
75									(1 120)	1 300	1 520	
80										(1 330)	1 580	1 710
90										(1 390)	1 680	1 850
100										(1 430)	1 770	1 980
110											1 850	2 080
120											1 920	2 180
130											(1 970)	2 270
140											(2 020)	2 350
150											(2 060)	2 420
160												(2 480)
180												(2 580)
200												(2 650)

increased and $\pm(k_{22} - k_{11})$ diminished, then λ is zero. If the gap is enclosed in a cage connected to one sphere, λ will always be positive since Sphere 1 is then the sphere insulated from the cage.

Substituting in (2),

$$V = \frac{s\epsilon/N}{1 + \lambda[(N_1/N) - 1]} \quad . \quad . \quad . \quad (2.2)$$

The effect of λ is to cause an asymmetry in the field, but this is small, and recent work on the mechanism of the spark would suggest that its influence might well be neglected in the present instance. Thus the field ϵ at the high-voltage or insulated sphere probably determines sparkover and, for a given spacing and sphere diameter, may be taken as a constant of the gas. Thus if V_i is the sparkover voltage for a symmetrical arrangement ($\lambda = 0$) and V_e that for an asymmetrical or earthed gap, then

$$\frac{V_i}{V_e} = 1 + \lambda\left(\frac{N_1}{N} - 1\right) \quad . \quad . \quad . \quad (2.3)$$

Recalling the discussion of λ, it is then deduced that

$V_i > V_e$ { (1) when the lower sphere is earthed, or indeed for most cases when the gap is horizontal.
(2) when a caged gap is used.

$V_i = V_e$ { (3) when the mid-point of the supply is earthed.
(4) when guard rings, etc., are used.

$V_i < V_e$ { (5) when the upper sphere is earthed and no ceiling earth-plate is used.

Cases (1) and (3) are in accordance with general experimental knowledge, (2) has been verified by Toepler,* (4) by Vanoni and Pieri,† and (5) by some German experiments communicated by Weicker.

The I.E.C. calibrations are based on experiments mainly carried out with the lower sphere earthed, so that λ is positive and may be calculated from

$$\lambda = \frac{(V_i/V_e) - 1}{(N_1/N) - 1} \quad . \quad . \quad . \quad . \quad (2.4)$$

The result is shown in Fig. 3. Although theoretically λ can vary from zero (symmetrical gap) to unity (large and complete, earthed enclosure), yet in practice it lies between about 0·2 and 0·7, increasing with increase of s/d or of sphere diameter. To a first approximation, λ should be inversely proportional to k‡ (the capacitance between the spheres) and proportional to k' (the capacitance to the surroundings), so that an "intrinsic" asymmetry λ_0 may be defined as

$$\lambda_0 = \frac{k\lambda}{k'} \quad . \quad . \quad . \quad . \quad . \quad (2.5)$$

Now k and k' may be calculated on the assumption that the potential at infinity is zero, whence λ_0 may be computed as shown in Fig. 4. Although λ_0 is nearly

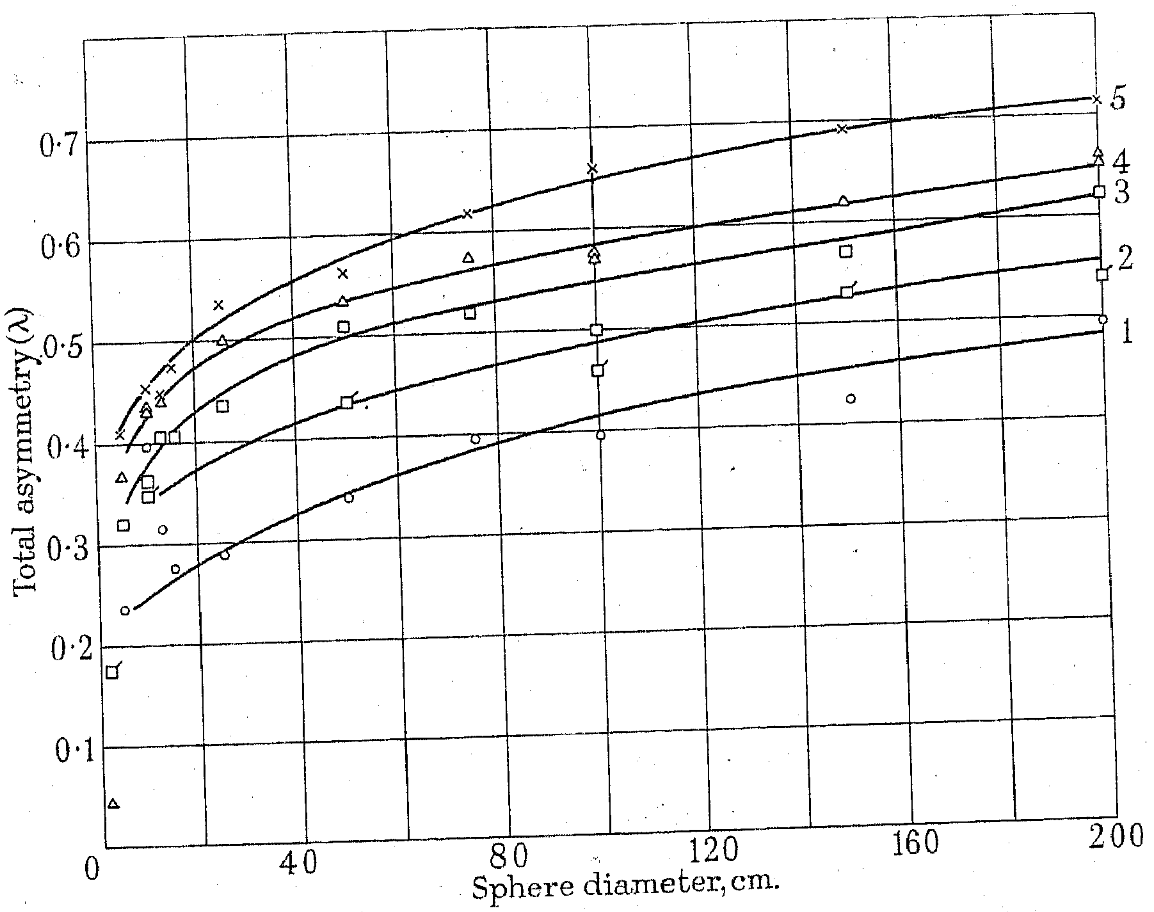


Fig. 3.—Total asymmetry of circuit.

1. —○— $s/d = 0\cdot4$.
2. —□̸— $s/d = 0\cdot5$.
3. —□— $s/d = 0\cdot6$.
4. —△— $s/d = 0\cdot75$ or $0\cdot8$.
5. —×— $s/d = 1\cdot0$.

---

* *Zeitschrift für technische Physik*, 1932, vol. 13, p. 386; *Elektrotechnische Zeitschrift*, 1932, vol. 53, p. 1219; *Archiv für Elektrotechnik*, 1936, vol. 30, p. 669; *Physikalische Zeitschrift*, 1934, vol. 35, p. 161.

† *L'Elettrotecnica*, 1935, vol. 22, p. 834, and 1937, vol. 24, p. 390; *Elektrotechnische Zeitschrift*, 1936, vol. 57, pp. 377, 412, and 1937, vol. 58, pp. 609, 1323; *Archiv für Elektrotechnik*, 1937, vol. 31, p. 342.

‡ A. Russell: "Alternating Currents," vol. 1, chap. 8.

independent of s/d except for small values, where it can only roughly be estimated, yet it increases with sphere diameter, particularly for smaller spheres. This may be explained on the basis that the size of laboratory and the effective size of enclosure are the same for smaller spheres, and thus the ratio of size of sphere to size of enclosure increases with sphere diameter, with a consequent increase in λ and in the true k'. But k' is actually computed on the assumption that the ratio is constant. Thus an apparent increase in λ_0 occurs. For large spheres the size of enclosure must be proportional to the size of sphere to a greater extent, since with the highest voltages all available space is generally used, while this would be uneconomical with smaller spheres and lower voltages, even in the same laboratory. Thus the theoretical conditions for k' are more nearly fulfilled and λ_0 is more nearly constant.

Since λ_0 is mainly determined by the earth plane, other external bodies need not be so carefully specified, provided they are more distant than is the earth plane.

Table 4*

Sphere diameter (cm.)	Up to 25	50	75	100	150	200
Minimum distance to earth (cm.) ..	$5d$	$4d$	$4d$	$3\cdot5d$	$3d$	$3d$
Maximum distance to earth (cm.) ..	$7d$	$6d$	$6d$	$5d$	$4d$	$4d$

* The distances are actually measured from the spark point of the high-voltage sphere. As regards the maximum distance, this also applies when $s/d < 0\cdot5$, to ensure that λ_0 is always positive.

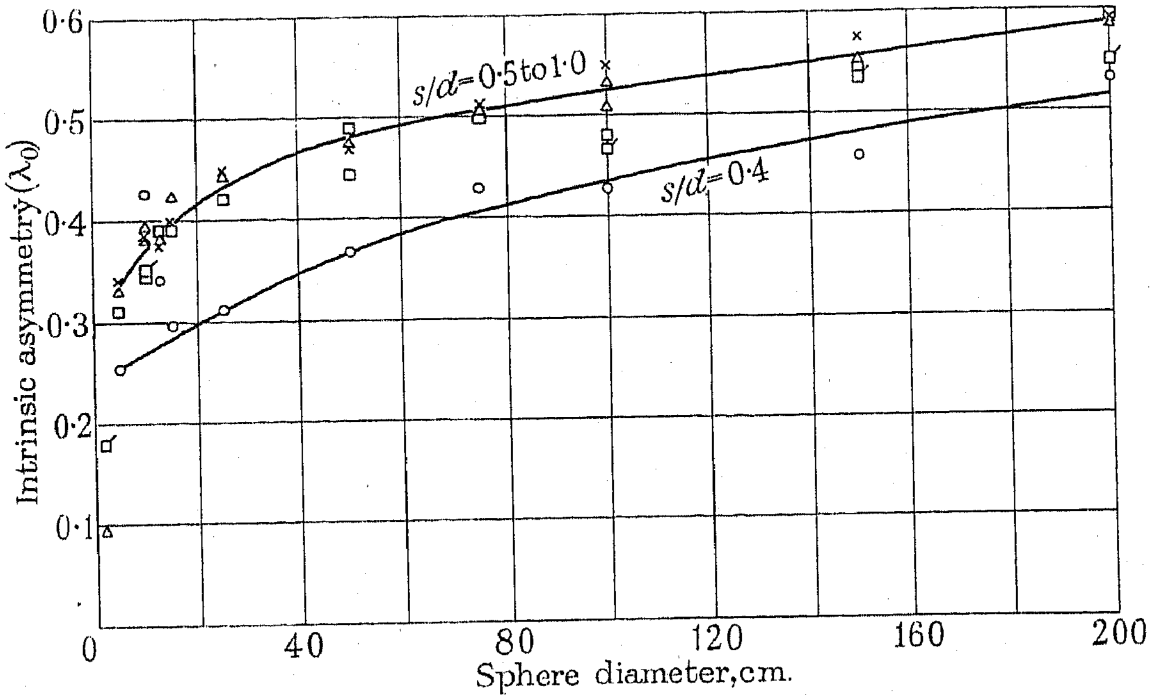


Fig. 4.—" Intrinsic " asymmetry of circuit.

○ $s/d = 0\cdot4$.
☐′ $s/d = 0\cdot5$.
☐ $s/d = 0\cdot6$.
△ $s/d = 0\cdot7$ or $0\cdot8$.
× $s/d = 1\cdot0$.

For values of s/d less than $0\cdot5$, the value of $[(N_1/N) - 1]$ is small and V_i is nearly equal to V_e; thus the magnitude of λ_0 (the asymmetry with respect to the surroundings) is not important and it is only necessary to ensure that the equivalent earth plane is nearer the earthed sphere than the insulated sphere, and that external bodies do not seriously distort the field in the gap. Accordingly the minimum distance of these bodies may be based on the spacing or on the voltage to be measured, which is convenient and economical of space when small voltages are to be measured with large spheres.* When s/d exceeds $0\cdot5$, then especially must the distance of the equivalent earth plane from the earthed sphere be determined by the sphere diameter, to ensure that λ_0 is of the correct order. The values adopted by the I.E.C. in these circumstances are as shown in Table 4. They are roughly in accord with the U.S.A. draft standards.

It is academically interesting, in view of the foregoing, to note that a first-approximation formula for the sphere-gap may be deduced theoretically. If the ionization coefficient is proportional to $(E - \epsilon_0)^2$, the Townsend–Schumann integral agrees with the Toepler–Stephenson formula, and gives, where E is the field at a distance x along the ionic path:—

$$\int_0^s (E - \epsilon_0)^2 dx = c^2 \quad . \quad . \quad . \quad . \quad (2.6)$$

To a first approximation for the sphere-gap,

$$E - \epsilon_0 = (\epsilon - \epsilon_0)\left(1 - \gamma\frac{x}{d}\right)$$

where

$\gamma = 4(N - 1)\dfrac{d}{s}\dfrac{\epsilon}{\epsilon - \epsilon_0} \rightarrow 18$ (roughly, for the larger spheres).

---

* The minimum distance from earth of the spark point of the high-voltage sphere actually adopted by the I.E.C., when $s < 0.5d$, is $10s$, $8s$, $7s$, $6s$, for 2- to 25-cm., 50- to 75-cm., 100-cm., and 150- to 200-cm. diameter spheres respectively. The minimum distance of extraneous bodies is taken as $[0\cdot25 + (U/300)]$ metres, where U is the crest voltage in kilovolts.

Substituting in the integral and rearranging,

$$\epsilon - \epsilon_0 = \frac{c}{\sqrt{s}}\left(1 - \gamma\frac{s}{d}\right)^{-\frac{1}{2}}$$

Thus $$\epsilon = \epsilon_0 + d^{-\frac{1}{2}}c\left[\sqrt{\left(\frac{d}{s}\right)} + \tfrac{1}{2}\gamma\sqrt{\left(\frac{s}{d}\right)}\right]$$

Substituting the values already given for ϵ_0, c, and also γ,

$$V_i = s\left\{24\cdot 75 + d^{-\frac{1}{2}} \times 5\cdot 95\left[\sqrt{\left(\frac{d}{s}\right)} + 9\sqrt{\left(\frac{s}{d}\right)}\right]\right\}/N \quad . \quad . \quad . \quad . \quad (2.7)$$

for symmetrical voltages, and

$$V_e = \frac{V_i}{1 + \lambda\left[(N_1/N) - 1\right]}$$

for one sphere earthed. In both cases the voltage given is the crest value in kilovolts. The formula gives fairly good agreement for larger spheres, but is essentially incapable of rigid practical application, or physical significance.

In a very asymmetrical and divergent field, such as is provided by the earthed sphere-gap at very wide spacings, sparkover occurs at very much lower voltages when the high-voltage electrode is positive than when it is negative. In such fields stable corona precedes the spark. The mechanism of such long sparks has recently been treated by Allibone,* and the present author has suggested† that this mechanism may be taken more generally and related to the occurrence of stable corona. Where stable corona does not so occur, as for smaller spacings of the sphere-gap, the field must first be distorted into a quasi corona-forming field by space charges, which are more easily formed near the negative electrode from positive ions which have a low mobility. Accordingly, for the range here considered, sparkover will, *ceteris paribus*, tend to begin at the negative electrode, which seems, to some extent, to be the case. If a slight asymmetry is produced by earthing the positive sphere, then, since the more intense field near the negative sphere should mainly determine the discharge, the reduction in sparkover voltage should be more or less proportional to the increase in the field at the high-voltage sphere. Since this ratio has already been shown to apply to power-frequency voltages, and since with the insulated gap there should be no polarity effect,‡ it follows that the negative unidirectional and impulse sparkover voltage should be equal to the power-frequency sparkover voltage. This is in agreement with the consensus of opinion for impulses of the standard form (1/50 microsecond) but for the form 1/5 microsecond the negative impulse voltage may be 5 % greater, and for still shorter impulses the divergence is not well known but probably greater.

If the negative sphere is earthed, then the reduction due to the asymmetry thereby introduced will not be so great since it is the field at the positive electrode which is increased, so that the positive impulse sparkover voltage should exceed the negative impulse sparkover voltage, but the ratio $V_e(+)/V_e(-)$* should still be less than the ratio V_i/V_e. Although considerable divergences exist between the results obtained by different experimenters, it was finally decided, for the present, to use values of $V_e(+)/V_e(-)$ determined in the U.S.A. and communicated to the I.E.C., and these values comply with the preceding condition. In addition, the values of λ_0 which applied to the American tests were of an order to comply with the I.E.C. Rules, which is necessary in order to ensure that $V_e(+)/V_e(-)$ is consistent with V_i/V_e. Continuous unidirectional voltages should agree with impulse voltages of the same respective sign, but there is little satisfactory evidence on this point. It may be mentioned, in passing, that the change of sign of the polarity effect occurs at a spacing of somewhat less than $2d$, where also corona begins to make its appearance before the spark, in accordance with the views expressed. Further, the validity of (2.6) and (2.7) is not affected by the space charge, which must form after the attainment of the critical voltage; since the sparkover-voltage/spacing curve for large spacings (where corona occurs) would, if extrapolated to small spacings (where corona does not occur), fall below the curve given by (2.7), so that the gap is too unstable to permit appreciable distortion without the eventual occurrence of sparkover. Finally, a corona-forming conductor near the gap can, if it causes electrons to appear in the latter, increase the sparkover voltage by neutralization of the positive space-charge. The proximity of such conductors, with their unpredictable effects, is to be avoided.

The preceding considerations show that the asymmetry λ_0 for spacings exceeding $0\cdot 5d$ seriously affects the possible accuracy of the sphere-gap, since the disposition of relatively remote parts of the circuit and of other bodies fundamentally influences the effect of earthing one sphere and the polarity effect. Every effort should therefore be made to use smaller spacings.

(4) EFFECT OF AIR DENSITY

As was indicated by the present author in 1927,† the application of Townsend's general discharge theorem to equation (1) gives

$$V = Ad\delta + B\sqrt{(d\delta)} \quad . \quad . \quad . \quad . \quad (3)$$

where A and B are functions of s/d, and δ is the relative air density. Thus the correction factor (K) for density might be written

$$K = \frac{Ad\delta + B\sqrt{(d\delta)}}{Ad + B\sqrt{d}} \quad . \quad . \quad . \quad (3.1)$$

or

$$K = \frac{A's\delta + B'\sqrt{(s\delta)}}{As + B\sqrt{s}} \quad . \quad . \quad . \quad (3.2)$$

where A' and B' are also functions of s/d. From this it is to be expected that K should be a function both of diameter and of spacing (or s/d), although Peek's formula, hitherto adopted, makes A and B constant, which is only a rough approximation. Subsequently Franck‡ made a fairly detailed study of the effect of density, which, as in the foregoing, indicated the influence both of spacing and of diameter. More recently Verplanck* has proposed a calculation for K which depends upon the value of s/d. When δ lies between 0·95 and 1·05, K is equal to δ, and very few experiments lie outside this range. Further, the extreme locations of electrical equipment as regards atmospheric conditions (more particularly as influenced by altitude) lie within a range for δ of 0·7 to 1·05. Over this range the value of K calculated by the various methods varies little with spacing or diameter. A complicated table for different values of s and d was not justified either by experimental bases or by the accuracy desired, and so a single series of mean values of K for all sphere-gaps was adopted which was found to correspond sufficiently closely to Peek's values of 25-cm. diameter spheres, given in Table 5.

---

* *Journal I.E.E.*, 1938, vol. 82, p. 513.

† In the discussion before The Institution on Dr. Allibone's paper, 3rd November, 1938. (Part of the discussion is repeated here for convenience of reference.)

‡ Table 2 should be valid for all types of voltages, but it is not so entitled on account of lack of experimental evidence.

* The impulse voltages correspond to the I.E.C. standard of 50 % sparkovers. As Allibone has shown (*Journal I.E.E.*, 1938, vol. 82, p. 671), this mode of definition affects the magnitude of the ratio $V(+)/V(-)$.

† "Electrical Discharges in Gases" (Ernest Benn, London, 1927).

‡ *Archiv für Elektrotechnik*, 1929, vol. 23, p. 226.

Table 5

δ	0·7	0·75	0·80	0·85	0·90	0·95	1·00	1·05	1·10
K	0·72	0·76	0·81	0·86	0·90	0·95	1·00	1·05	1·09

---

* *Electrical Engineering*, 1938, vol. 57, p. 45.

INSTITUTION NOTES

HONORARY MEMBER

At the Ordinary Meeting of The Institution held on the 2nd February, 1939, the President announced that the Council had elected Sir Archibald Page, Past-President, to be an Honorary Member.

FARADAY MEDAL

At the same meeting the President also announced that the Council had made the Seventeenth Award of the Faraday Medal to Dr. W. D. Coolidge, Director of Research, General Electric Co., Schenectady, U.S.A.

VOLUNTARY NATIONAL SERVICE

The President has accepted an invitation to serve upon the Central Register Advisory Council which the Minister of Labour and the Lord Privy Seal have appointed. It consists of representatives of the Service Departments, employers, and the major professional scientific and technical organizations, and will advise the Minister in regard to the work of the Central Register of Engineers and Scientists. The Register is being established by the Ministry of Labour and will, it is understood, be used in the event of a national emergency for co-ordinating scientific and technical personnel, and for selecting for both Government and other work additional personnel with scientific and technical qualifications, and persons qualified for administrative posts.

As referred to on page 46 of the National Service Handbook, The Institution has been asked to co-operate in the work of compiling the Register, and a questionnaire for issue to members is in course of preparation.

SCHOLARSHIPS

The Secretary desires to draw the attention of members to the following Institution Scholarships:—

Duddell Scholarship (value £150 per annum for 3 years).

Open to British subjects under 19 years of age on the 1st July who have passed a matriculation or equivalent examination, and who desire to take up a whole-time day course in electrical engineering.

Preference will be given to candidates whose fathers or a near relative are, or have been, members of The Institution.

Ferranti Scholarship (value £250 per annum for 2 years).

For whole-time research or post-graduate work. Open to British subjects under 26 years of age on the 1st July, who have been Students or Graduates of The Institution for at least 2 years and have taken either (*a*) a whole-time course in electrical engineering of at least 3 years and obtained a degree or diploma; or (*b*) a whole-time course in science of at least 3 years and obtained an honours degree, provided that in the final examination for such degree they have passed in "physics," or "electro-chemistry," or "electro-metallurgy."

Preference will be given to candidates whose fathers are, or have been, members of The Institution.

Swan Memorial Scholarship (value £120 for 1 year).

The conditions are similar to those for the Ferranti Scholarship, except that the age limit is 27 years on the 1st July and that candidates need not be members of The Institution. Preference will be given to candidates who were born in the County Borough of Sunderland, or resided there for at least 7 years, or were educated at Sunderland Technical College.

Silvanus Thompson Scholarship (value £100 per annum, plus tuition fees, for 2 years).

Open to British subjects who have served a minimum apprenticeship (or its equivalent) of 3 years at an approved works and are under 22 years of age on the 1st July, and who desire to take up a whole-time day course in electrical engineering.

The closing date for receiving nominations for this year's awards of Scholarships is the 15th April. Any member desirous of obtaining more detailed information should apply to the Secretary.

THE ENGINEERS' GERMAN CIRCLE

Monday, 27th March, 1939, at The Institution of Mechanical Engineers, Storey's Gate, S.W.1, at 6 p.m. (tea at 5.30 p.m.). Lecture on "Die Bedeutung von Zeitstudien für die Werksverwaltung" ("The Importance of Time Studies for Works Organization"), by Prof. F. Meyenberg. The proceedings will be in German. The meeting is open to all I.E.E. members.

INFORMAL MEETINGS

216TH INFORMAL MEETING (24TH OCTOBER, 1938)

Chairman: The President.

Subject of Discussion: "Engineering Training in Relation to Present Conditions" (introduced by the President, Dr. A. P. M. Fleming, C.B.E., M.Sc.).

Speakers: Messrs. I. O. Hockmeyer, B.Sc.(Eng.), H. E. Knight, W. S. Sholl, S. C. Bartholomew, M.B.E., J. H. Johnson, H. J. Bullard, A. Morgan, E. Kilburn Scott, G. R. Davies, Prof. W. Jackson, D.Sc., D.Phil., W. T. O'Dea, B.Sc.Tech., Messrs. W. J. John, B.Sc.(Eng.), J. W. Leach, F. Jervis Smith, E. Ambrose, and P. H. Pettifor, B.Sc.(Eng.).

217TH INFORMAL MEETING (7TH NOVEMBER, 1938)

Chairman: Mr. H. Brierley.

Subject of Discussion: "To What Extent is Hydro-Electric Enterprise Economically Justified?" [introduced by Lt.-Comdr. R. B. Fairthorne, R.N.(Ret.)].

Speakers: Messrs. C. H. de Nordwall, W. S. Sholl, E. Rosenberg, Dr.techn., E. Kilburn Scott, R. H. Upton, M.Eng., E. S. Ritter, P. L. Spencer, Capt. K. H. Tuson, R.E., Messrs. J. K. Hunter, A. F. W. Richards, F. Jervis Smith, G. H. Fowler, and R. W. Mountain, B.Sc.(Eng.).

218TH INFORMAL MEETING (21ST NOVEMBER, 1938)

Chairman: Mr. A. G. Kemsley.

Subject of Discussion: "Distribution and Low-Voltage Short-Circuit Conditions in Densely Loaded Areas" (introduced by Mr. J. W. Leach).

Speakers: Messrs. J. H. Wadman, W. S. Sholl, H. Lloyd Williams, B.Sc., J. M. Goodall, G. H. Fowler, C. J. O. Garrard, M.Sc., Forbes Jackson, A. Morgan, A. W. Metcalf, G. L. E. Metz, C. H. de Nordwall, P. J. Higgs, B.Sc.(Eng.), E. Stracey-Cheel, M.C., B.Sc.(Eng.), S. W. Melsom, W. F. Sands, H. Simmonds, J. C. Chaytor, H. S. Petch, B.Sc.(Eng.), C. Kibblewhite, and A. G. Kemsley.

219TH INFORMAL MEETING (5TH DECEMBER, 1938)

Chairman: Mr. J. R. Jones.

Subject of Discussion: "Electrical Welding as applied to Structures" (introduced by Dr. J. H. Paterson).

Speakers: Messrs. A. Morgan, F. Jervis Smith, S. A. Stevens, P. L. Spencer, G. Davidson, I. O. Hockmeyer, B.Sc.(Eng.), and J. R. Jones.

220TH INFORMAL MEETING (19TH DECEMBER, 1938)

Chairman: Mr. S. C. Bartholomew, M.B.E.

Subject of Discussion: "Poynting's Law and the Transmission of Energy" (introduced by Prof. W. M. Thornton, O.B.E., D.Sc., D.Eng.).

Speakers: Messrs. A. J. Good, J. E. Taylor, W. P. Wood, E. F. Clark, B.A., B.Sc.(Eng.), J. F. Perrin, J. Greig, B.Sc.(Eng.), E. S. Ritter, and S. C. Bartholomew, M.B.E.

221ST INFORMAL MEETING (9TH JANUARY, 1939)

Chairman: Mr. W. A. Ritchie.

Subject of Discussion: "Recent Developments in Electro-Deposition" (introduced by Mr. A. W. Hothersall, M.Sc.).

Speakers: Messrs. A. Morgan, F. Jervis Smith, P. L. Spencer, A. L. Fielding, R. H. Upton, M.Eng., P. P. Wheelwright, J. C. Chaytor, S. A. Stevens, and G. E. Gardam.

222ND INFORMAL MEETING (23RD JANUARY, 1939)

Chairman: Mr. F. Jervis Smith.

Subject of Discussion: "Adequate Wiring" [introduced by Mr. H. G. Taylor, M.Sc.(Eng.)].

Speakers: Messrs. F. C. Raphael, E. Jacobi, Mrs. H. Bentham, Messrs. A. Morgan, F. H. D. Sewell, F. Jackson, Major F. A. Sclater, O.B.E., M.C., M.A., Messrs. H. Bentham, H. J. Bullard, H. B. Bailey, G. Davidson, J. A. Prowse, C. R. H. Stewart, E. A. Pinto, H. Brierley, and F. Jervis Smith.

PROCEEDINGS OF THE TRANSMISSION SECTION

29TH MEETING OF THE TRANSMISSION SECTION, 9TH NOVEMBER, 1938

Mr. J. L. Eve, the retiring Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 11th May, 1938, were taken as read and were confirmed and signed.

Mr. Eve announced the Council's award of Premiums (see vol. 82, page 699) for papers read before the Section during the session 1937–1938. He then vacated the chair, which was taken by the new Chairman, Mr. S. R. Siviour.

A vote of thanks to Mr. Eve for his services as Chairman during the session 1937–1938, proposed by Mr. F. W. Purse and seconded by Mr. H. W. Grimmitt, was carried with acclamation.

Mr. Siviour then delivered his Inaugural Address (see page 9).

A vote of thanks to the Chairman for his Address, proposed by Dr. P. Dunsheath, O.B.E., M.A., and seconded by Mr. C. W. Marshall, B.Sc., was carried with acclamation.

30TH MEETING OF THE TRANSMISSION SECTION, 14TH DECEMBER, 1938

Mr. S. R. Siviour, Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 9th November, 1938, were taken as read and were confirmed and signed.

Professor J. C. van Staveren then delivered a lecture on "The Organization, Work, and Laboratories of the N.V. tot Keuring van Electrotechnische Materialen (K.E.M.A.), the Dutch Testing Station for Electrical Material."

A vote of thanks to the lecturer, proposed by Dr. A. P. M. Fleming, C.B.E., M.Sc. (President), and seconded by Mr. R. Borlase Matthews, was carried with acclamation.

PROCEEDINGS OF THE WIRELESS SECTION

146TH MEETING OF THE WIRELESS SECTION, 2ND NOVEMBER, 1938

Mr. T. Wadsworth, M.Sc., the retiring Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 4th May, 1938, were taken as read and were confirmed and signed.

Mr. Wadsworth announced the Council's award of Premiums (see vol. 82, page 698) for papers read before the Section during the session 1937–1938. He then vacated the chair, which was taken by the new Chairman, Mr. A. J. Gill.

A vote of thanks to Mr. Wadsworth for his services as Chairman during the session 1937–1938, proposed by Mr. H. Bishop, B.Sc.(Eng.), and seconded by Mr. R. P. G. Denman, M.A., was carried with acclamation.

Mr. Gill then delivered his Inaugural Address (see page 248).

A vote of thanks to the Chairman for his Address, proposed by Mr. Wadsworth, was carried with acclamation.

14TH INFORMAL MEETING OF THE WIRELESS SECTION, 22ND NOVEMBER, 1938

Mr. A. J. Gill, B.Sc.(Eng.), Chairman of the Section, took the chair at 6.30 p.m.

The minutes of the Informal Meeting held on the 15th March, 1938, were taken as read and were confirmed and signed.

A discussion, opened by Mr. T. E. Goldup, took place on " Receiving Valves."

At the conclusion of the discussion a vote of thanks was accorded to Mr. Goldup for his introductory remarks.

147TH MEETING OF THE WIRELESS SECTION, 7TH DECEMBER, 1938

Mr. A. J. Gill, B.Sc.(Eng.), Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 2nd November, 1938, were taken as read and were confirmed and signed.

The following papers were read and discussed: " Long Feeders for Transmitting Wide Side-Bands, with reference to the Alexandra Palace Aerial-Feeder System," by Messrs. E. C. Cork, B.Sc.(Eng.), Associate Member, and J. L. Pawsey, Ph.D.; and " E.M.I. Cathode-Ray Television Transmission Tubes," by Messrs. J. D. McGee, M.Sc., Ph.D., and H. G. Lubszynski, Dr. Ing.

A vote of thanks to the authors, moved by the Chairman, was carried with acclamation.

148TH MEETING OF THE WIRELESS SECTION, 4TH JANUARY, 1939

Mr. A. J. Gill, B.Sc.(Eng.), Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting held on the 7th December, 1938, were taken as read and were confirmed and signed.

Sir Noel Ashbridge, B.Sc.(Eng.), then delivered a lecture entitled " Broadcasting and Television."

A vote of thanks to the lecturer, moved by the Chairman, was carried with acclamation.

15TH INFORMAL MEETING OF THE WIRELESS SECTION, 24TH JANUARY, 1939

Mr. A. J. Gill, B.Sc.(Eng.), Chairman of the Section, took the chair at 6.30 p.m.

The minutes of the Informal Meeting held on the 22nd November, 1938, were taken as read and were confirmed and signed.

A discussion, opened by Mr. M. V. Callendar, took place on " Automatic Tuning Devices."

At the conclusion of the discussion a vote of thanks was accorded to Mr. Callendar for his introductory remarks.

ELECTIONS AND TRANSFERS

At the Ordinary Meeting of The Institution held on the 23rd February, 1939, the following elections and transfers were effected:—

Elections

Associate Members

Daniel, Frederick John, B.Sc.(Eng.).
Dore, Leslie John.
Freeman, Arthur Charles, B.E.
Gilmour, Alexander.
Gokarn, Prabhakar Ramchandra, B.Sc.(Eng.).
Goodman, Roy Parish, B.E.
Hami, Mehmed Baha, B.Sc.(Eng.).
Hawkesley, Edgar.
Helliwell, Joseph Brook, B.Sc.Tech.
James, Harry Langford.
Kubale, John Charles.
Linde, Alexander James.
Rickett, Owen Charles.
Ridpath, Claude Herbert E.
Sykes, Jack.
Vann, Cecil John, B.Sc. (Eng.).

Companions

Hurcomb, Sir Cyril.
Wood, Charles Eustace O.

Associates

Bloore, Charles George.
Dymond, Eric Alfred W.
Haig, Claud Leopold.
Holt, Robert Dickinson.
Manley, Victor Charles.
Owens, Walter Herbert.
Russell, Arthur.
Sillar, Laurence Gilbert.
Whyte, Robert Paisley.
Worby, Arthur Ernest.
Wright, James Henry.

Graduates

Allison, Stanley Sydney H.
Andrews, Manasser Mathews.
Bennett, Albert Edward, B.Sc.
Birks, Kenneth William.
Calver, Wilfred Harry.
Chan, U. Kin.
Clarke, Harold.
Edgcumbe, Piers Richard.
Epstein, Theodor, Dipl.Ing.
Fisher, George Albert.
Goode, Thomas Ryall, B.E.
Hassan, Mas'ud.
Hughes, Douglas.
Husbands, Arthur Stephen, B.Sc.(Eng.).
Jack, William Alexander.
Jackson, William Leslie.
Jameson, John Francis.
Jenkins, William Bingham.
Lunny, Francis Michael, B.E.
McKenzie, Edgar Donald M.
Parry, Arnold Holmes.
Pausey, James Thomas B., B.Eng.
Pennant, Nigel Douglas, B.A.
Pinder, William.
Ritchie, Richard Thomson.
Robinson, John Leslie.
Rodger, John Thomas.
Scholes, Ernest Heywood.
Scott, Dan.
Spraggons, Alfred James.
Stevens, Stanley Walter.
Tandy, Thomas Henry.
Tempest, Ronald.
Traylor, John Davies, B.Sc.
Turner, Leslie William.
Tysoe, Gerald Charles, B.Sc.
Vaughan, Eric Hugh, B.Sc.
Whitham, John Willoughby.
Wood, Ernest.

Students

Atkinson, Bryan William.
Barr-Wells, Donald Reynell.
Baxter, George Farquharson.
Bharucha, Khaikhosru Rustomji.
Bhatia, Prem Lal.
Bolton, Wallace.
Bradbury, John James.
Butler, Frederick Walter.
Butterworth, Eric Gordon.
Chacon, Ernest Eric.
Common, Raymond Percy.
Coombes, Roy Lester.
Crow, Bernard Henry.
Dalaya, Tikaram Laxman
Dew, Ronald Thomas.
Diaper, Eric Thomas.
Dong, Ching Tsung.
Drake, John Barnard.
Drew, John Marshall, B.A.
Edwards, William Thomas.
Everhart, George Marlow.
Fife, John Howard.
Frodsham, Anthony Freer.
Gaylard, Richard Percival.
Ghosh, Samarendra Nath.
Gupta, Sat Parkash N.
Hansford, Reginald Frederick.
Henson, Cecil Stanley.
Higson, Hugh Ward.
Hollaway, Bernard.
Ilott, Eric Charles.
Jansen, Pieter Cornelis.
Johnson, Arthur Basil.
Kingdon, Henry Thomas.
Kinloch, Colin David.
KrishnaMurty, Velidandla Bala.
Lovatt, Clifford Roy.
Lurie, Irving.
McBreen, James Patrick.
McGregor, Robert Howell.
Mander, Richard James.
Mason, Nigel Anthony K.
Mason, Stanley Hugh.
Mellor, Edward Vincent, B.A.
Milne, Stanley Watt.
Morris, Joseph Thomas.
Morrison, Ronald James.
Naylor, Frederick Dennis.
Owens, John Geoffrey.
Pearce, Kenneth William.
Platt, Harold Edward.
Rao, Penumarty Venkata C.
Rata, Samuel.
Rickers, Maurice Ivor.
Robertson, Granville Cyril E.
Sanders, John Nicholas.
Sathyavagheeswaran, Subramania Iyer.
Scampton, Thomas Reginald.
Scott, Kenneth Frederick.
Setty, Belgod Manjiah A.
Sheard, John Raymond.
Sheppard, Stanley Herbert.
Singh, Sat Paul.
Singh, Sudarshan.
Smith, Leslie George.
Sperring, Francis Edwin.
Srinivasan, Nattu.
Stafford, Herbert William H.
Stuchbury, Kenneth John H.
Talbot, Ronald Henry.
Tandan, Ram Kumar, M.Sc.
Tonoff, Anatole Nicholas.
Trivett, Oscar Edward.
Tuckett, Donald.
Turford, Montague John.
Umrigar, Dhanjisha Manekji.
Urben, Trevor Fortescue A.
Vernon, Wesley.
Walker, Sydney Alfred.
Weir, Stanley Kenneth.
Wells, William Albert.
West, Roger Frankland.
Wharton, William.
Williams, Owain Samuel G.
Williamson, Denis.
Winder, Enrico Mario.
Zuberi, Mahmudul Hasan K.

Transfers

Associate Member to Member

Espley, Dennis Clark, M.Eng.
Ganguly, Shiba Prosad.
Gardiner, Herbert William B., B.Sc.(Eng.).
Kennedy, Geoffrey Farrer, M.A.
Little, Gilbert Joseph S., B.Sc.
Spurr, Reginald Dade.
Steele, Ernest Wilson.
Swale, William Eric.
Thouless, Kenneth James, M.A.
Ure, William, B.Sc.

Associate to Associate Member

Barnacle, Alfred Benedict.
Bulley, Henry Samuel.
Eddershaw, Bernard.
Hawley, William George.
Wiltshire, George Reginald.

Graduate to Associate Member

Algar, Herbert William.
Aziez, Mohamed Idrose.
Ball, James Ellis W., B.Sc.(Eng.).
Bennett, George, B.Eng.
Bowles, Fred.
Champion, Bernard Harden.
Chapman, John Henry.
Clark, Gilbert.
Connock, Sidney Henry G., B.Sc.(Eng.).
Dummer, Geoffrey William A.
Finnimore, Thomas Charles.
Gallon, Cyril.
Girdlestone, Richard Owen.
Gray, George William E.
Hayward, Doyle Walton.
Hiles, Leslie Fitzallen.
Hogben, Roland Stanley.
Journet, Robert Edwin.
Kelly, Trevor Erle, B.Sc.
Lambe, Herbert George F.
Lawlor, James Butler S.
McNeill, William Alexander, B.Sc.Tech.
Millyard, Harold.
Morgan, Reginald Ian, B.Sc.
Parker, Arthur John.
Patel, Shivabhai Purusjottamdas, B.Sc.(Eng.).
Peet, Claud George, Major, M.C., B.Sc.(Eng.).
Redman, Richard Henry, B.Sc.(Eng.).
Reiss, Conrad, B.Sc.Tech.
Ritchie, Douglas Loudoun, B.Sc.
Stebbing, Geoffrey Charles.
Tarbatt, George Edric.
Wainwright, Hector Aitken, B.Eng.
Warbrick, Cecil.
Wood, William Stanley.

The following transfers were effected by the Council at their meeting held on the 2nd February, 1939:—

Student to Graduate

Allan, Alexander Frederick G.
Atkinson, Norman.
Bakhru, Hasso Jethanand.
Barker, Harold.
Best, Denis, B.Eng.
Bivand, Eric Ernest.
Boden, George Harry.
Burch, Donald Barrington.
Choksey, Dorab Khursed.
Clotworthy, John Alexander, B.Sc.
Coates, Jack.
Cole, Gordon Leslie.
Dawson, James Gordon, B.Sc.(Eng.).
Dean, James.
Fry, Anthony Ellerton R., B.Sc.
Gibson, Clarance.
Hamilton, James Lawrie.
Houston, David.
Howell, Cecil Moreton, B.Sc.
Jeffery, Edred.
Jones, Arthur Howel, B.A.
Le Fevre, Alan William.
Maclaren, David Muir.
Menon, Bhakti Vilas D.
Pearce, Albert John.
Permentiers, Rene Joseph.
Planer, Felix Ernest, B.Sc.
Reece, Edward D'Oyly.
Reekie, Gavin Ralston.
Reid-Jones, John William.
Robertson, James Young.
Shepperd, Charles Gordon.
Sims, Eric Arthur.
Southern, Christopher John.
Stace, Francis Nigel.
White, Harry William.
Wilkins, Leonard Royce.

The following transfers were also effected by the Council at their meeting held on the 23rd February, 1939:—

Student to Graduate

Andrew, Jeffrey.
Asim, Syed Mohammed.
Ayers, Eric Wilfred, B.Sc. (Eng.).
Bamford, Harry.
Bayes, Geoffrey Gilbert, B.Sc.
Bittles, Samuel George, B.Sc.
Deshpande, Prabhakar Raghunath.
Devaney, Henry John.
Don, Denis Thomas K.
Evans, Gordon Edward, B.Sc.
Greaves, Frederick Edward.
Haussauer, Edmond Jules.
Hilton, Herman.
Howson, Frank William.
Kay, Alexander Cecil, B.Sc.Tech.
Lund, James Arthur.
Meeson, Edwin Laurence, B.Sc.(Eng.).
Mowl, Arthur Richard.
Newby, Thomas Hobbs.
Oxley, George Clarence.
Paris, Edward Cowper.
Puri, Kishori Lal.
Roberts, Denis Norman.
Smart, David Lorimer, B.Sc.Tech.
Truter, Albert Macnamara, B.Sc.(Eng.).
Wassilissin, Anatole, B.Sc. (Eng.).
Weinstock, Jack.
Wilkinson, Norman Edward R.

ACCESSIONS TO THE REFERENCE LIBRARY

[NOTE.—The books cannot be purchased at The Institution; the names of the publishers and the prices are given only for the convenience of members; (*) denotes that the book is also in the Lending Library.]

PLATT, M., *M.Eng.* Automobile brakes and brake testing. 8vo. vii + 136 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1938.) 3*s.* 6*d.*

POTTER, M. H. Electric welding. A practical text covering the fundamental principles and applications of the various types of electric arc welding, including the use of power tube rectifiers. 8vo. 126 pp. (Chicago: American Technical Society, 1938.) 5*s.* (*)

RADIO CORPORATION OF AMERICA. Television. Collected addresses and papers on the future of the new art and its recent technical developments. vol. 1, viii + 452 pp. vol. 2, vii + 435 pp. 8vo. (New York: RCA Institutes Technical Press, 1936–37.)

READ, A. B. Lighting the home. 4to. 72 + 40 pp. (London: Country Life, Ltd., 1938.) 10*s.* 6*d.*

RICHARDSON, R. C. H. The commissioning of electrical plant and associated problems. 8vo. xvi + 363 pp. (London: Chapman and Hall, Ltd., 1938.) 21*s.* (*)

RISSIK, H. The rectification of alternating current. 8vo. x + 219 pp. (London: English Universities Press, Ltd., 1938.) 21*s.* (*)

ROGET, S. R., *M.A.* A dictionary of electrical terms, including telegraphy, telephony, and wireless. 3rd ed. sm. 8vo. v + 425 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1938.) 8*s.* 6*d.*

RUDORFF, D. W. Steam generators. 8vo. xi + 182 pp. (London: Charles Griffin and Co., Ltd., 1938.) 10*s.* (*)

—— The superheater in modern power plant. 8vo. ix + 293 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1938.). 21*s.* (*)

SACHS, K., *Dr.techn.* Die ortsfesten Anlagen elektrischer Bahnen. 4to. xii + 321 pp. + 8 pl. (Zürich: Orell Füssli, 1938.) 48 *Sw. francs.*

SAYERS, H. M. The economic principles of electrical distribution. 8vo. vii + 169 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1938.) 12*s.* 6*d.* (*)

SCHEIBE, A., *Dr.* Piezoelektrizität des Quarzes. 8vo. xii + 233 pp. (Dresden: Theodor Steinkopff, 1938.) *RM.* 21.

SCHWAIGER, A., *Dr.Ing.* Der Schutzbereich von Blitzableitern. Neue Regeln für den Bau von Blitz-Fangvorrichtungen. 8vo. 115 pp. (München: R. Oldenbourg, 1938.) *RM.* 5.

SCROGGIE, M. G. Radio laboratory handbook. sm. 8vo. x + 384 pp. (London: Iliffe and Sons, Ltd., 1938.) 8*s.* 6*d.* (*)

SMITH, C. F., *D.Sc.* Practical alternating currents and alternating current testing. 18th ed. 8vo. 420 pp. (Manchester: The Scientific Publishing Co.) 10*s.* (*)

—— The practical testing of dynamos and motors. 14th ed. 8vo. 271 pp. (Manchester: The Scientific Publishing Co.) 7*s.* 6*d.* (*)

SMITH, S. P., *D.Sc.* Problems in electrical engineering, with answers. 3rd ed. sm. 8vo. xxiii + 267 pp. (London: Constable and Co., Ltd., 1938.) 6*s.* (*)

SPEAKMAN, J. C., *M.Sc., Ph.D.* Modern atomic theory: an elementary introduction. 8vo. 207 pp. (London: Edward Arnold and Co., 1938.) 6*s.*

STARR, A. T., *M.A., Ph.D.* Electric circuits and wave filters. 2nd ed. xiv + 476 pp. (London: Sir Isaac Pitman and Sons, Ltd., 1938.) 21*s.* (*)

STOLLER, H. M., AUSTIN, F. E., and SEEGER, E. W. Small motors, transformers, electromagnets. A practical presentation of design and construction data for small motors, small low- and high-tension transformers, electromagnets and induction coils. 8vo. 320 pp. (Chicago: American Technical Society, 1938.) 12*s.* 6*d.* (*)

STRUTT, M. J. O., *Dr.* Moderne Mehrgitterelektronenröhren. 2 Bd[e]. 8vo. (Berlin: Julius Springer, 1937–38.)

Bd. 1, Bau.—Arbeitsweise.—Eigenschaften. vi + 131 pp. *RM.* 12.60.
Bd. 2, Elektrophysikalische Grundlagen. iv + 144 pp. *RM.* 13.15.

TIMOSHENKO, S. Strength of materials. 2 pt. 8vo. (London: Macmillan and Co., Ltd., 1936–38.)

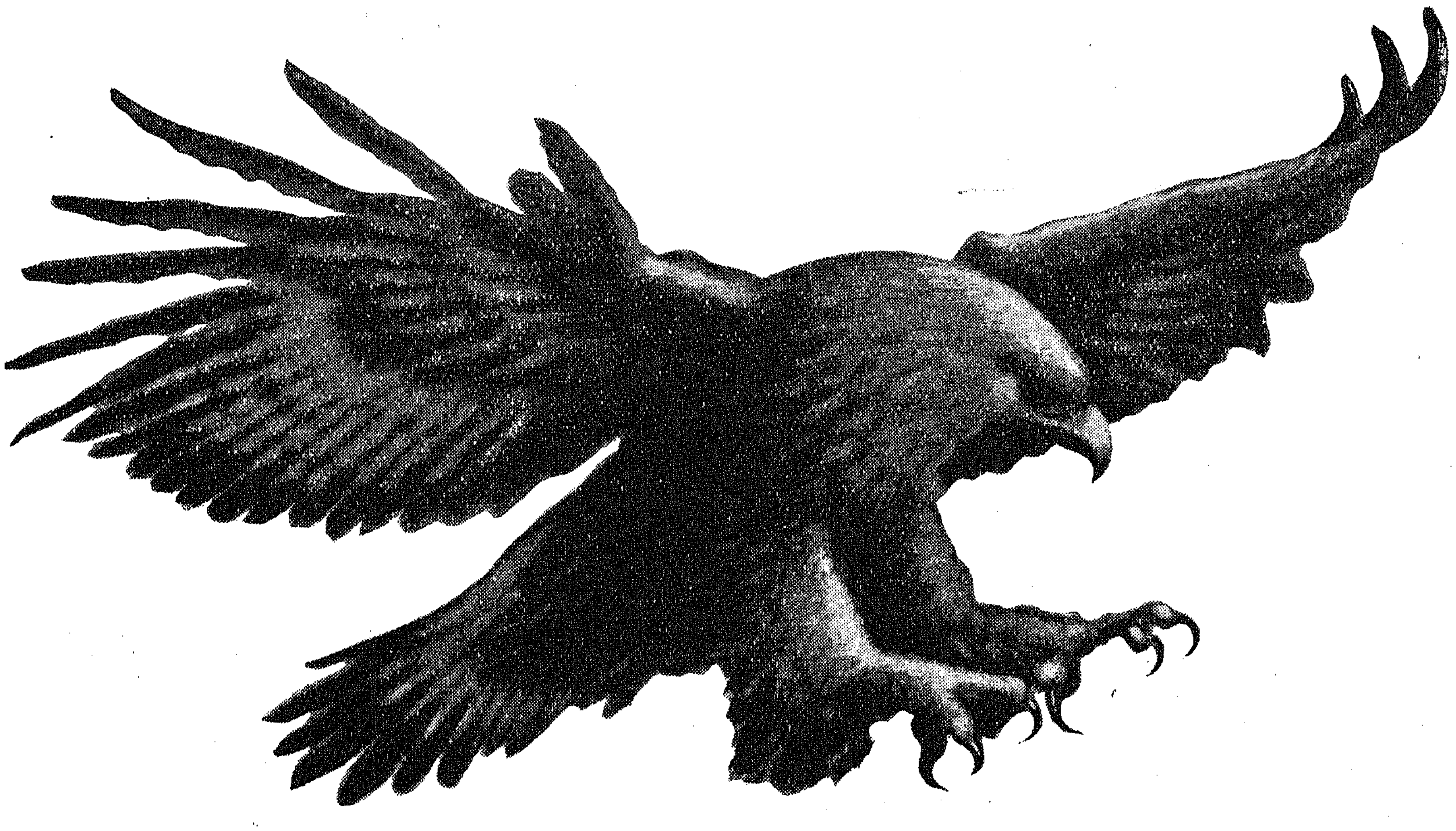
pt. 1, Elementary theory and problems. xii + 1–368 pp. 15*s.*
pt. 2, Advanced theory and problems. xi + 401–735 pp. 18*s.*

VAN BRUNT, G. A., and ROE, A. C. Winding alternating-current motor coils. 8vo. viii + 281 pp. (New York; London: McGraw-Hill Publishing Co., Ltd., 1938.) 18*s.* (*)

WHEATCROFT, E. L. E. Gaseous electrical conductors. 8vo. xi + 265 pp. (Oxford: Clarendon Press, 1938.) 21*s.* (*)

WILMAN, C. W. Automatic telephony. 2nd ed. 8vo. vi + 208 pp. (London: The Technical Press Ltd., 1938.) 10*s.* 6*d.* (*)

WILSON, H. A. Modern physics. 2nd ed. xv + 432 pp. (London: Blackie and Son, Ltd., 1937.) 30*s.* (*)



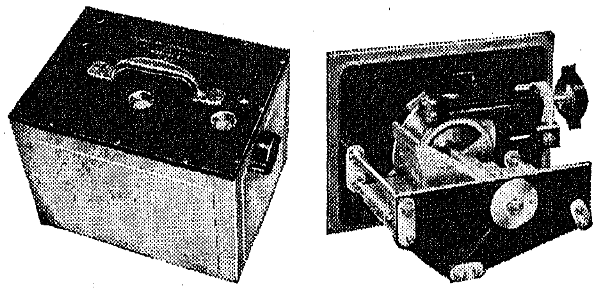
LAWFUL PREY

"There is hardly anything in the world that some man cannot make a little worse and sell a little cheaper; and the people who consider price only are this man's lawful prey."

MR. JOHN RUSKIN is, of course, the author of this oft-quoted statement, and although it has the familiar Ruskin air of rather sniffy disapproval, there is yet a great deal of sound sense in it.

Not that one disapproves of low prices in themselves. To make things a little cheaper is an admirable achievement; and for many purposes it does not even matter if the cheapness involves some loss of efficiency. "Good enough for its purpose" is a perfectly reasonable phrase, condescendingly though it is so often used.

So far as we are concerned, we tend rather to the reverse. Most of the work we produce is "a little better and a little dearer," and our lawful "prey" is the man who wants something produced of unusual quality, precision and accuracy. We are staffed and equipped to produce fine work and so we do not pretend to compete for jobs in which cutting to the last tenth of a penny is the vital consideration.



VARIABLE AIR CONDENSERS TYPES 11, 16 AND 18 HAVE:—

- Quartz Insulation.
- A reading accuracy of 1 part in 20,000 at full scale.
- Back lash which is negligible compared with recording accuracy.

Recently one of these condensers was returned to us after three years' continuous use on a production job. The maximum calibration error was 0.12 $\mu\mu$F.

MUIRHEAD

MUIRHEAD AND COMPANY LIMITED, ELMERS END, BECKENHAM, KENT. TELEPHONE: BECKENHAM 0041-0042.

FOR OVER 60 YEARS DESIGNERS & MAKERS OF PRECISION INSTRUMENTS

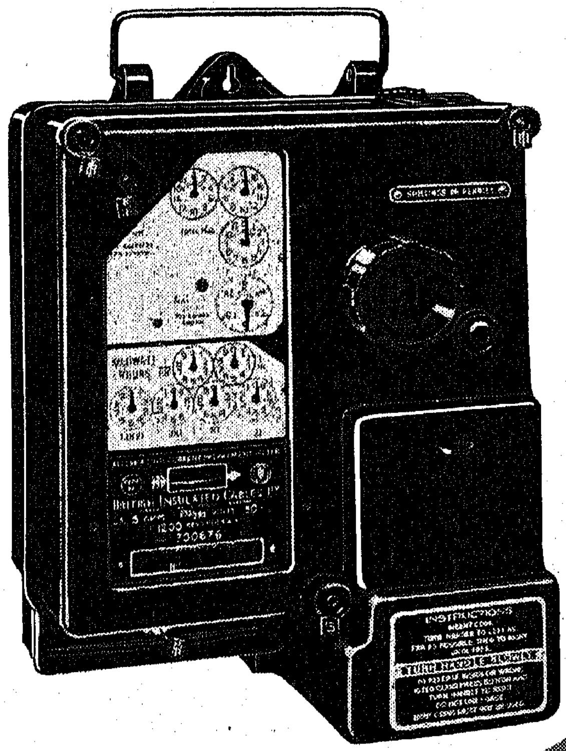
C.R.C. 8

SYMBOLS OF VALUE..... PAST AND PRESENT

ROMAN AUREUS

This fine specimen of a Gold Aureus of the time of Nero has a bust on the obverse with the simple inscription, "Nero Caesar." On the reverse Nero is shown standing, his head radiated, in his left hand a Victory and in his right hand a laurel branch.

The **B.I.** Trade Mark shown on the right is also a token of value. Almost since the birth of the electrical industry the **B.I.** Trade Mark has represented the highest standards of reliability and economy as applied to the whole varied range of **B.I.** manufactures, including **B.I.** Meters, of which one type is shewn below.



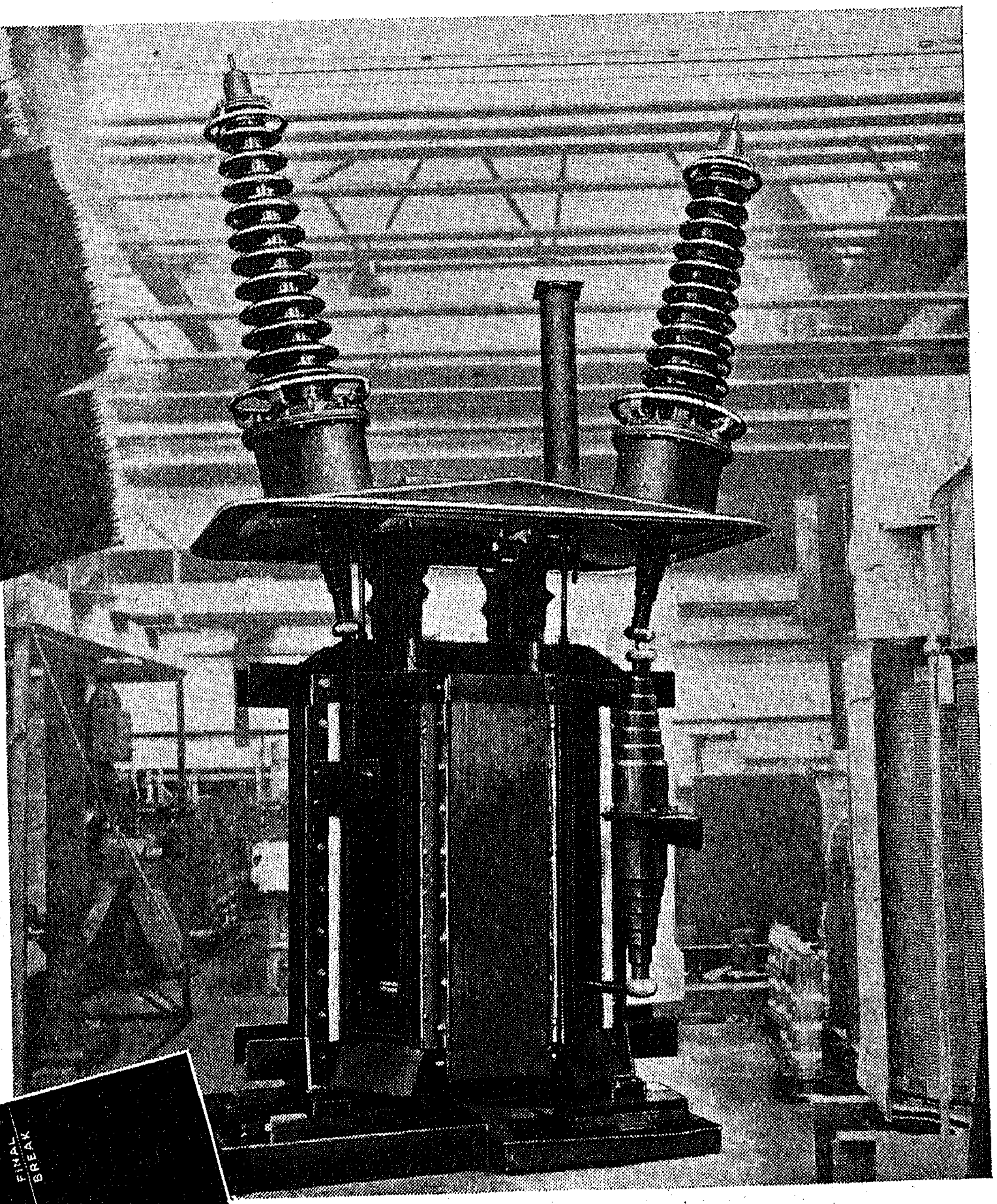
B.I. Dual Coin Prepayment Meter, Types M. & M.D.T., approved by the Electricity Commissioners for use on 200/250 volt, 50 cycle single phase two wire circuits. Write for special folder with full details. British Patent Numbers 347794, 414069, 464684. Appln. No. 18782/37.

B.I.

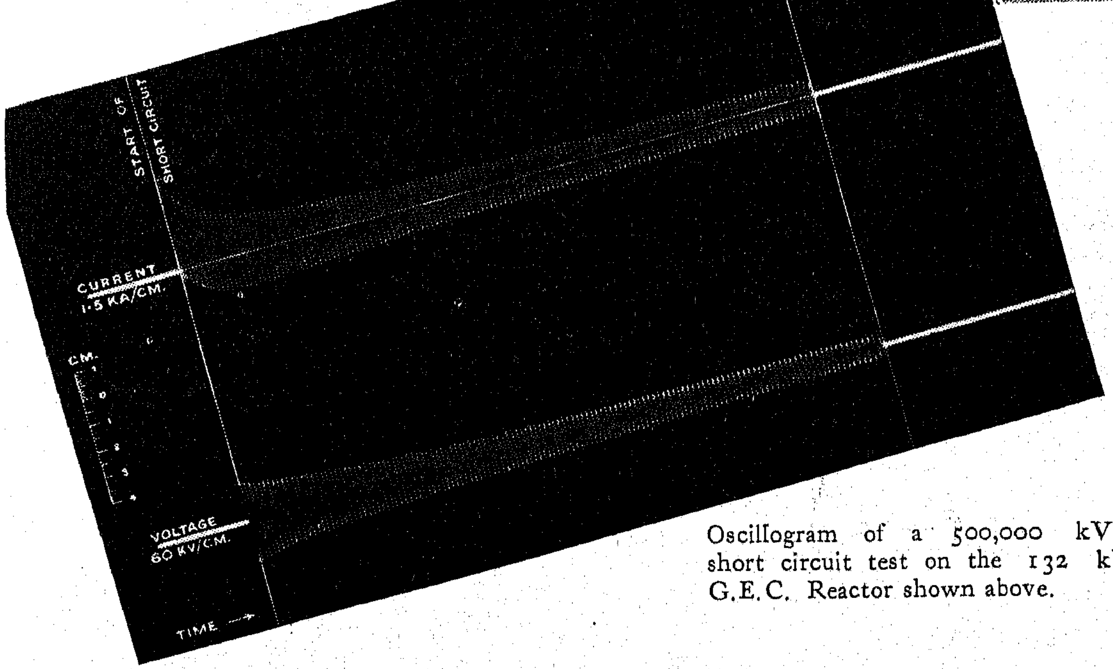
BRITISH INSULATED CABLES LTD., PRESCOT, LANCS.
Tel. No. Prescot 6571. *London Office*, Surrey House, Embankment, W.C. 2. Tel. No. Temple Bar 7722

G.E.C. OIL IMMERSED REACTORS

Proved & Tested for all Capacities and Duties



Here is one phase of a 3-phase bank of G.E.C. Oil Immersed Reactors shown removed from the tank.



Oscillogram of a 500,000 kVA short circuit test on the 132 kV G.E.C. Reactor shown above.

Two features of especial value in G.E.C. Reactors are:—

1. MAXIMUM POSSIBLE RIGIDITY OF LEADS
2. COMPACTNESS OF DESIGN

The floor space needed is quite small

Ask for a copy of Technical Description No. 213 which gives full information about G.E.C. Oil Immersed Reactors.

ALL G.E.C. OIL IMMERSED REACTORS ARE TESTED AND PROVED IN THE G.E.C. HIGH POWER TESTING STATION

Advt. of The General Electric Co., Ltd., Head Office: Magnet House, Kingsway, London, W.C.2.

Copyright
Colonel Sir
Thomas F. Purves
Exclusive Licensees
Members of the C.M.A.

The product of an unequalled combination of co-ordinated Research and long practical experience

MEMBERS OF THE C.M.A.

- The Anchor Cable Co. Ltd.
- British Insulated Cables Ltd.
- Callender's Cable & Construction Co. Ltd.
- The Craigpark Electric Cable Co. Ltd.
- Crompton Parkinson Ltd. (Derby Cables Ltd.)
- The Enfield Cable Works Ltd.
- Edison Swan Cables Ltd.
- W. T. Glover & Co. Ltd.
- Greengate and Irwell Rubber Co. Ltd.
- W. T. Henley's Telegraph Works Co. Ltd.
- The India Rubber Gutta-Percha and Telegraph Works Co. Ltd. (The Silvertown Co.)
- Johnson & Phillips Ltd.
- Liverpool Electric Cable Co. Ltd.
- The London Electric Wire Co. and Smiths Ltd.
- The Macintosh Cable Co. Ltd.
- The Metropolitan Electric Cable & Construction Co. Ltd.
- Pirelli-General Cable Works Ltd. (General Electric Co. Ltd.)
- St. Helens Cable & Rubber Co. Ltd.
- Siemens Brothers & Co. Ltd. (Siemens Electric Lamps and Supplies Ltd.)
- Standard Telephones & Cables Ltd.
- Union Cable Co. Ltd.

The C.M.A. offers you the combined resources and experience of all the best cable makers in the United Kingdom. A C.M.A. Cable is a quality product recognised to be the best of its kind, which ensures safety and in the long run effects considerable economy.

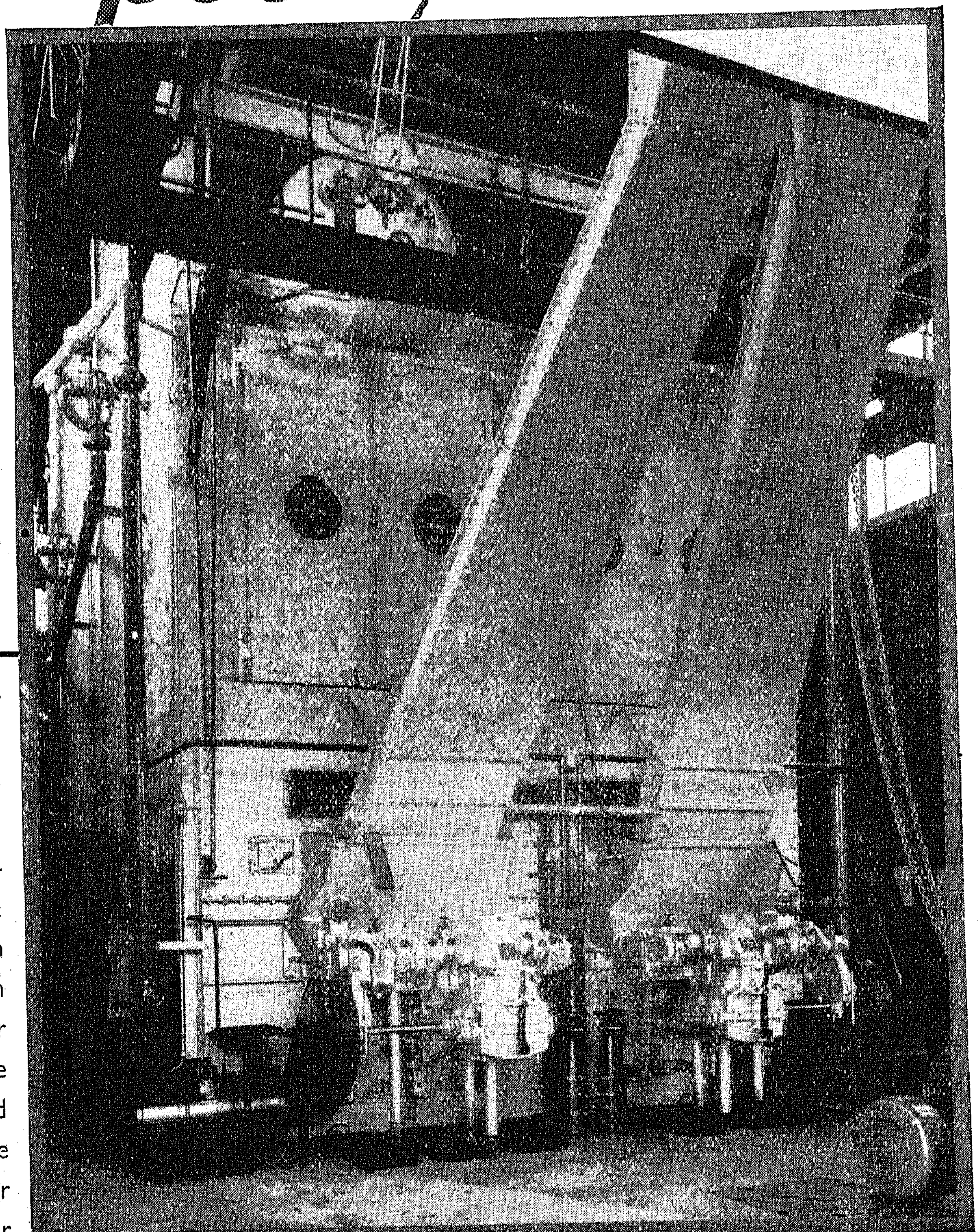
C.M.A.

C.M.A. Regd. Trade Mark Nos. 422219-20-21
NONAZO Regd. Trade Mark No. 458865

CABLES

Advert. of the Cable Makers' Association, High Holborn House, 52-54 High Holborn, W.C.1. *Phone: Holborn 7633*

The Shoemaker's child is NOT always poorly shod



CONSISTENT with the policy of ensuring the best equipment in our Plant, the boilerhouse of our Dumbarton Works has been renewed recently, and the photograph reproduced shows the two Babcock & Wilcox W.I.F. Boilers installed each for an evaporation of 11080 lbs. of steam per hour at 200 lbs./sq. in. Each boiler is fired with a Babcock-Erith Marine Type Stoker. The Babcock Calorized Diamond Soot Blowers, Babcock Clyde Soot Blowers, and all valves and boiler mountings were manufactured at our Dumbarton Works. The installation is equipped for the testing of different fuels on the retort type stokers. This change in boiler equipment has resulted in a seven-fold increase in steam capacity with a reduction of approximately 50% in floor area compared with the old boilerhouse.

BABCOCK & WILCOX LTD. BABCOCK HOUSE, FARRINGDON ST.
LONDON, E.C.4.

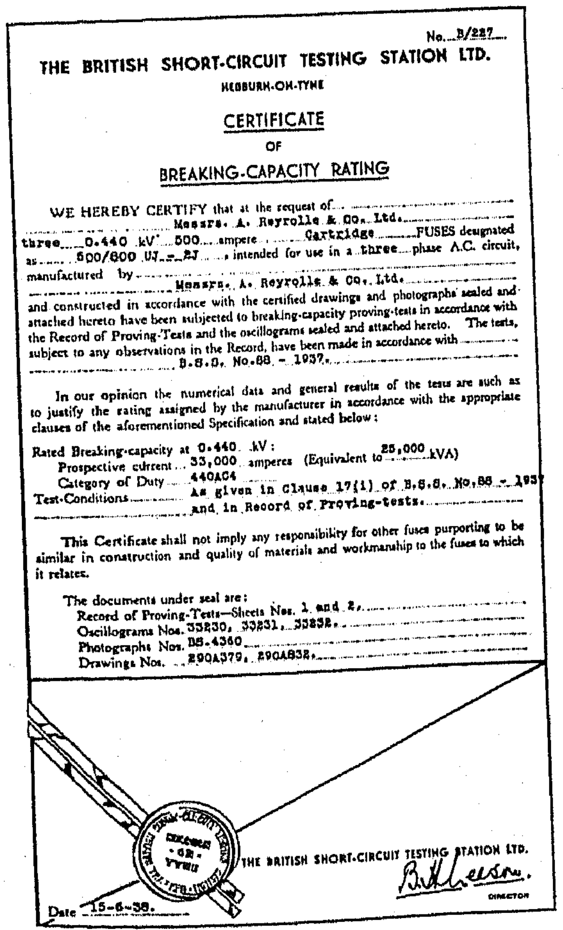
. . . of international acceptance
K.W.H.
1/100
1/10 DIVISIO
1000
100
10
1
PROPERTY OF
HOLLINWOOD FERRANTI ENGLAND
R/KWH
300
A
V
~ TYPE F.L.
No
LINE
LOAD
FERRANTI
Meters
FERRANTI LTD. HOLLINWOOD, LANCS. London Office Bush House, Aldwych W.C.2.

A QUESTION ABOUT YOUR FUSES

Do they comply in construction and performance with the British Standard requirements set out in B.S.88-1937 ?

Performance includes temperature-rise, fusing-factor, and breaking-capacity ; and certificates of type-tests relating to these must be available for fuses complying with B.S.88-1937

USE
REYROLLE
CARTRIDGE
FUSES
AND
SLEEP
SOUNDLY



No. B/227

THE BRITISH SHORT-CIRCUIT TESTING STATION LTD.
HEBBURN-ON-TYNE

CERTIFICATE
OF
BREAKING-CAPACITY RATING

WE HEREBY CERTIFY that at the request of Messrs. A. Reyrolle & Co. Ltd. Cartridge FUSES designated three 0.440 kV 500 ampere as 500/600 UJ - 2J intended for use in a three phase A.C. circuit, manufactured by Messrs. A. Reyrolle & Co. Ltd. and constructed in accordance with the certified drawings and photographs sealed and attached hereto have been subjected to breaking-capacity proving-tests in accordance with the Record of Proving-Tests and the oscillograms sealed and attached hereto. The tests, subject to any observations in the Record, have been made in accordance with B.S.S. No.88 - 1937.

In our opinion the numerical data and general results of the tests are such as to justify the rating assigned by the manufacturer in accordance with the appropriate clauses of the aforementioned Specification and stated below :

Rated Breaking-capacity at 0.440 kV :
Prospective current 33,000 amperes (Equivalent to 25,000 kVA)
Category of Duty 440AC4
Test-Conditions As given in Clause 17(1) of B.S.S. No.88 - 1937 and in Record of Proving-tests.

This Certificate shall not imply any responsibility for other fuses purporting to be similar in construction and quality of materials and workmanship to the fuses to which it relates.

The documents under seal are :
Record of Proving-Tests—Sheets Nos. 1 and 2.
Oscillograms Nos. 33230, 33231, 33232.
Photographs Nos. BS.4360
Drawings Nos. 290A379, 290A832.

THE BRITISH SHORT-CIRCUIT TESTING STATION LTD.
B. H. Leeson.
DIRECTOR

Date 15-6-38.

One of a range of certificates of breaking-capacity rating of Reyrolle cartridge-fuses

As a result of nicely-balanced design and sound construction based on unsurpassed facilities for research and manufacture

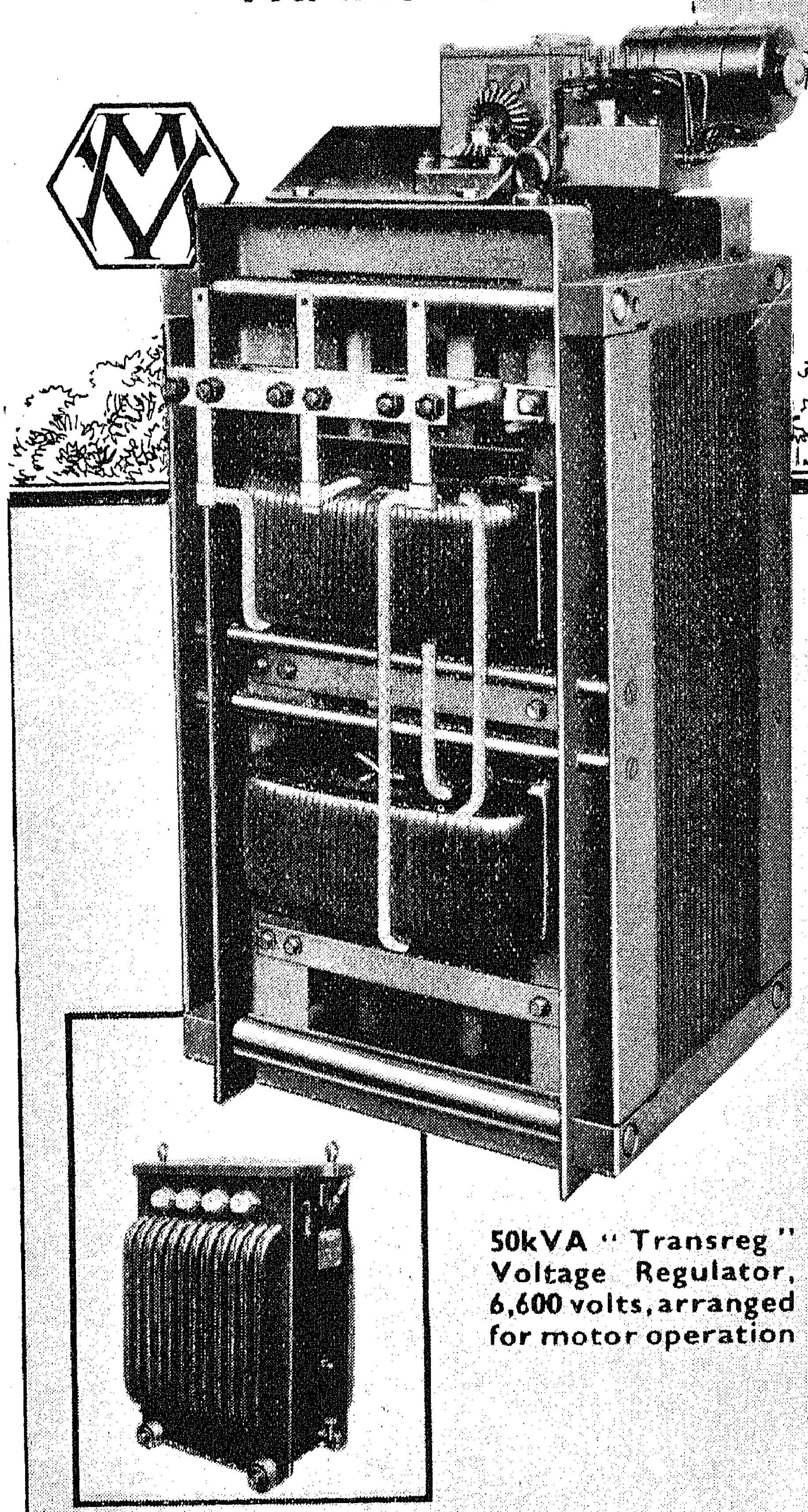
REYROLLE CARTRIDGE-FUSES COMPLY WITH B.S.88-1937 AND THE NECESSARY CERTIFICATES ARE AVAILABLE

REYROLLE & CO LTD
HEAD OFFICE AND WORKS
HEBBURN-ON-TYNE ENGLAND

METROVICK

"TRANSREG"

TRANSFORMER VOLTAGE REGULATOR



50kVA "Transreg" Voltage Regulator, 6,600 volts, arranged for motor operation

for RURAL AND RESIDENTIAL DISTRICTS

- Smooth Voltage Control No Steps
- Any range of voltage regulation
- Hand operation or Automatic Control
- Quiet operation
- No maintenance

Write for leaflet No. 391/5-1 on this subject

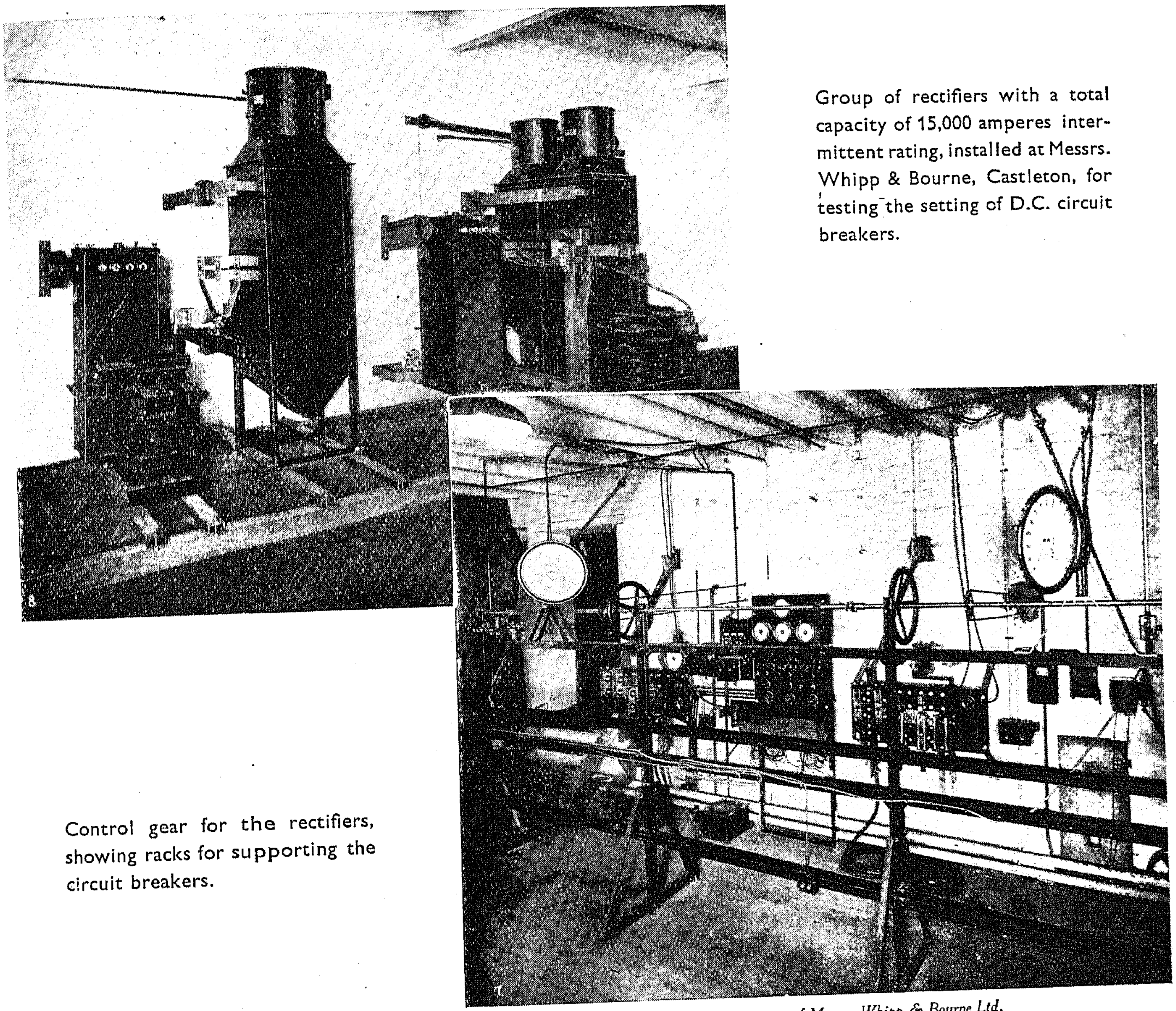
METROPOLITAN Vickers
ELECTRICAL CO., LTD.
TRAFFORD PARK ··· MANCHESTER 17.

Metrovick's light product

COSMOS LAMPS

E/R801

TESTING
D.C. CIRCUIT BREAKERS



Group of rectifiers with a total capacity of 15,000 amperes intermittent rating, installed at Messrs. Whipp & Bourne, Castleton, for testing the setting of D.C. circuit breakers.

Control gear for the rectifiers, showing racks for supporting the circuit breakers.

Photographs by courtesy of Messrs. Whipp & Bourne Ltd.

Westinghouse COPPER-OXIDE

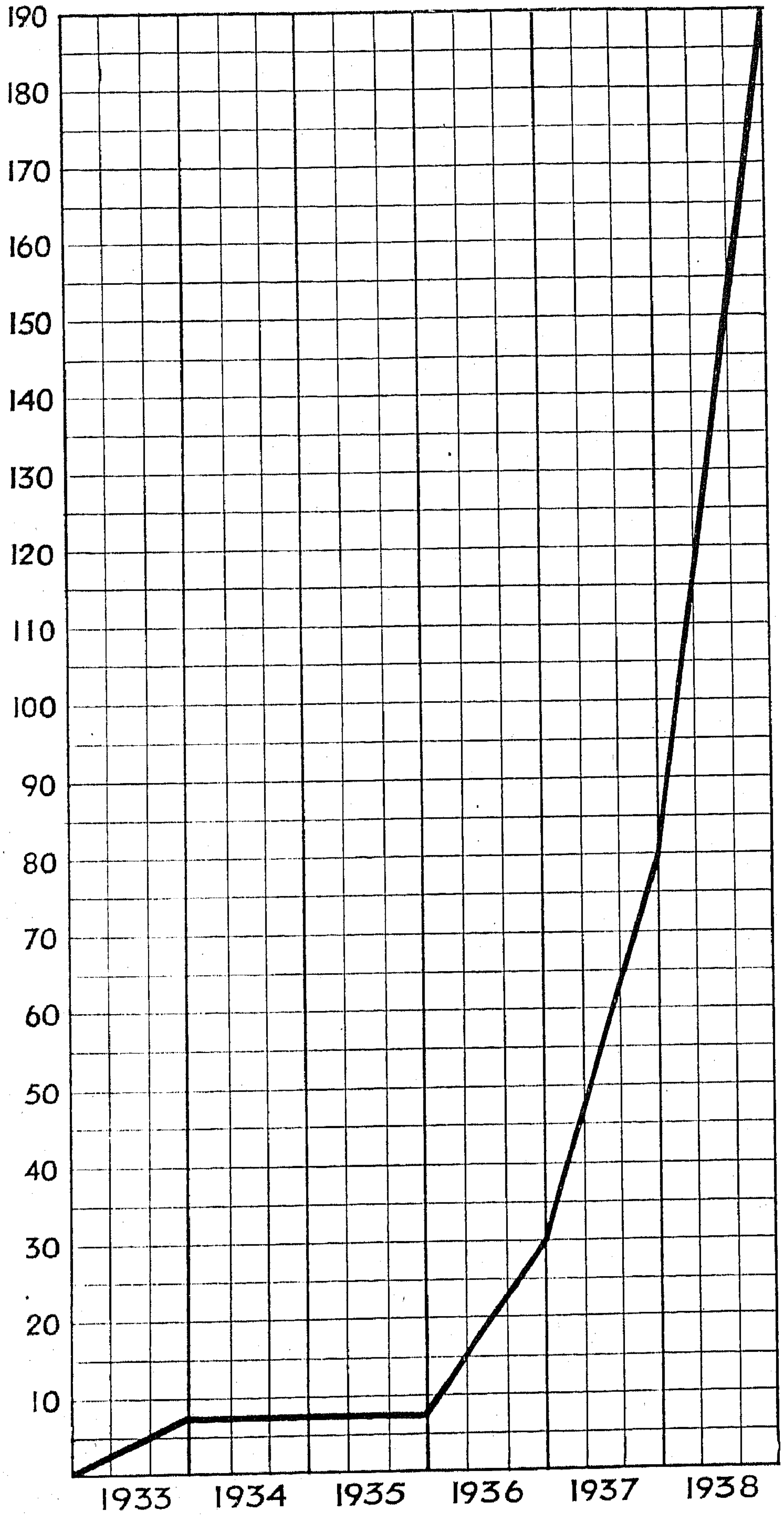
METAL RECTIFIERS

Write for descriptive pamphlet No. 11 to Dept. I.E.E.

WESTINGHOUSE BRAKE & SIGNAL CO. LTD.
82 York Way, King's Cross, London, N.1.

STYRENATION

PROGRESS



The accompanying graph completed at the end of 1938, shows the number of Styrenated joints, terminations and plugs in actual commercial service on cables of varying voltages up to 66 kV. ensuring freedom from compound migration troubles. In addition to these, a large amount of similar work has been, and is being, carried out and submitted to exhaustive tests in our factory, where research work is constantly in progress.

The applications of our Styrene technique are manifold. We are always at your service to consider your particular problems and to recommend the most suitable application for your requirements.

Standard Telephones and Cables Limited

NORTH WOOLWICH LONDON, E.16

Telephone: Albert Dock 1401

BRANCHES AND REPRESENTATIVES THROUGHOUT THE WORLD

£120 SAVED PER ANNUM
TYPE A.P.F. WITH COVER REMOVED

A manufacturer is saving £123 . 5 . 8 per annum by using a Dubilier condenser. His original tariff, a graded scale, averaged 1d. per unit. By improving the power factor with a Dubilier Power Factor Correction Condenser from ·87 to ·95 he was able to transfer to a much more advantageous tariff, which averaged ·85d. per unit for the first 26,250 units per quarter and ·75d. per unit for the balance. His annual consumption is 162,350 units and his account has now been reduced from £676 . 9 . 2 to £553 . 3 . 6. As this saving cannot be effected without great reliability, a Dubilier Power Factor Correction Condenser, which has no moving parts, is installed, assuring him of many years of trouble-free service.

Reliability is of greater importance than first cost, and in the long run it is more economical to buy Dubilier Power Factor Correction Condensers.

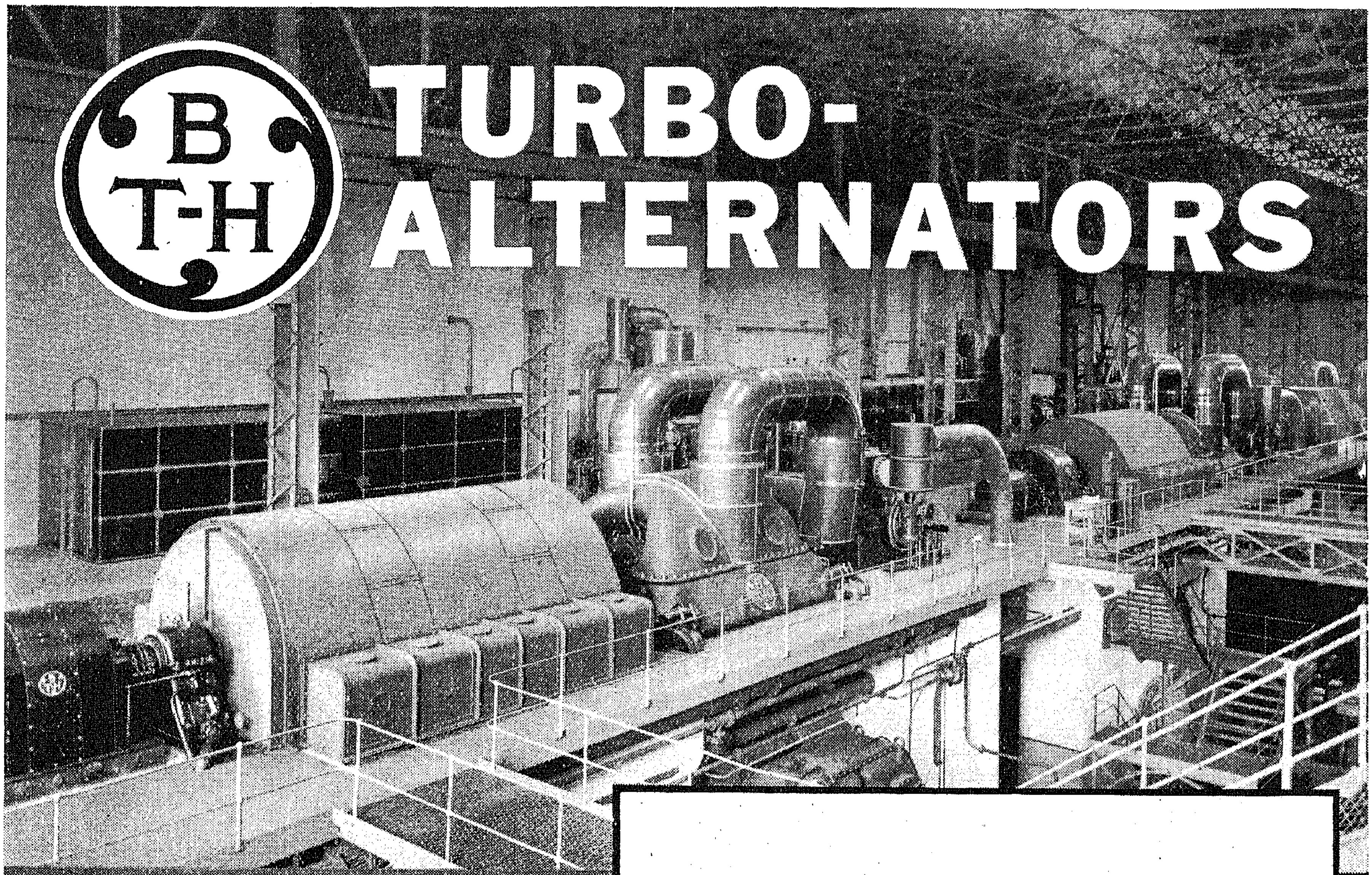
DUBILIER

POWER FACTOR CONDENSERS

DUBILIER CONDENSER CO. (1925) LTD., DUCON WORKS, VICTORIA ROAD, NORTH ACTON, LONDON, W.3

C. R. Casson, P.F.7

TURBO-ALTERNATORS



LONGFORD POWER STATION COVENTRY CORPORATION

The whole of the Turbine Plant in this station is of BTH manufacture and includes:—

Two - 30,000 KW., 33,000 volt,

and

Two – 20,000 KW., 6,600 volt,

TURBO-ALTERNATORS

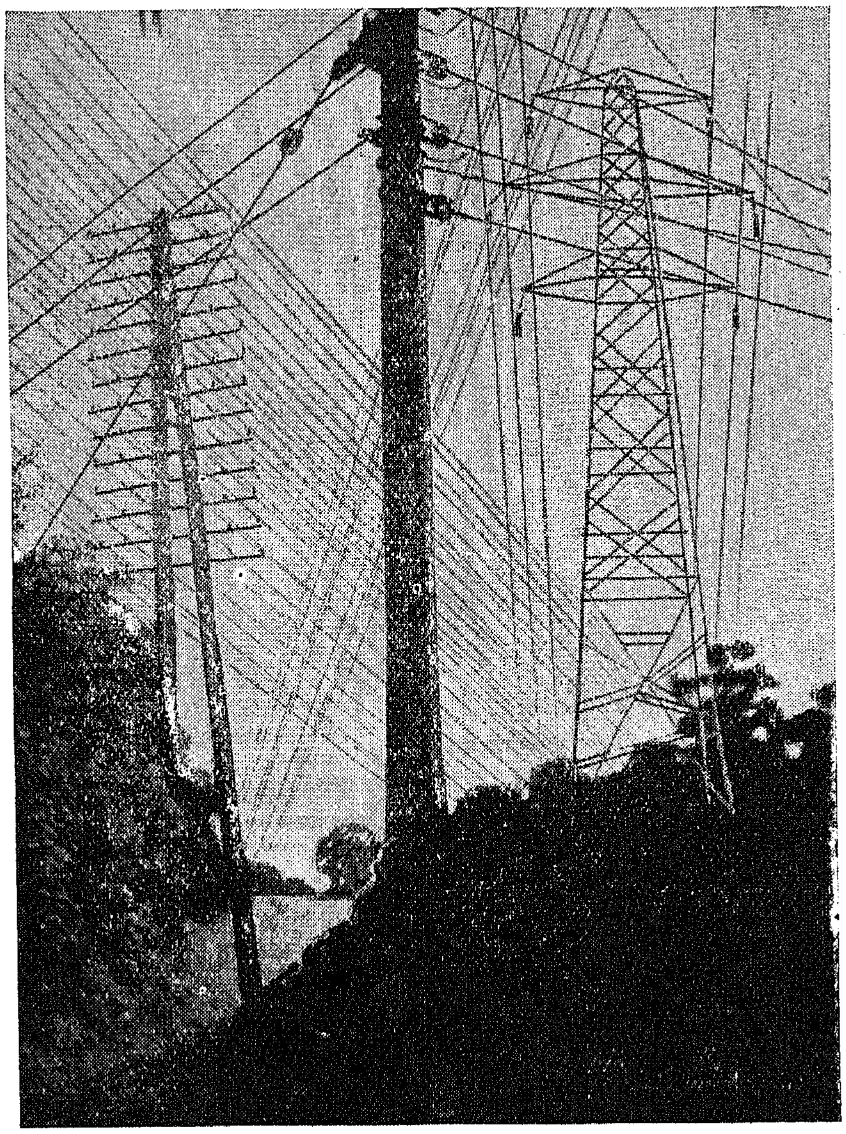
A third 30,000 KW., 33,000 volt, set is now on order making the total capacity 130,000 KW.

For Turbine Plant
ANY TYPE—
ANY CAPACITY
Send us
your enquiries

BTH RUGBY

THE BRITISH THOMSON-HOUSTON COMPANY LIMITED, RUGBY, ENGLAND.

A2671



ANACOS
REGD.

OVERHEAD LINES
in
COPPER
CADMIUM-COPPER
or BRONZE
for
TELEPHONE and TELEGRAPH LINES
POWER TRANSMISSION LINES
TROLLEY WIRES

Our Technical Dept. will supply you with data, and we shall be pleased to quote for your special requirements.

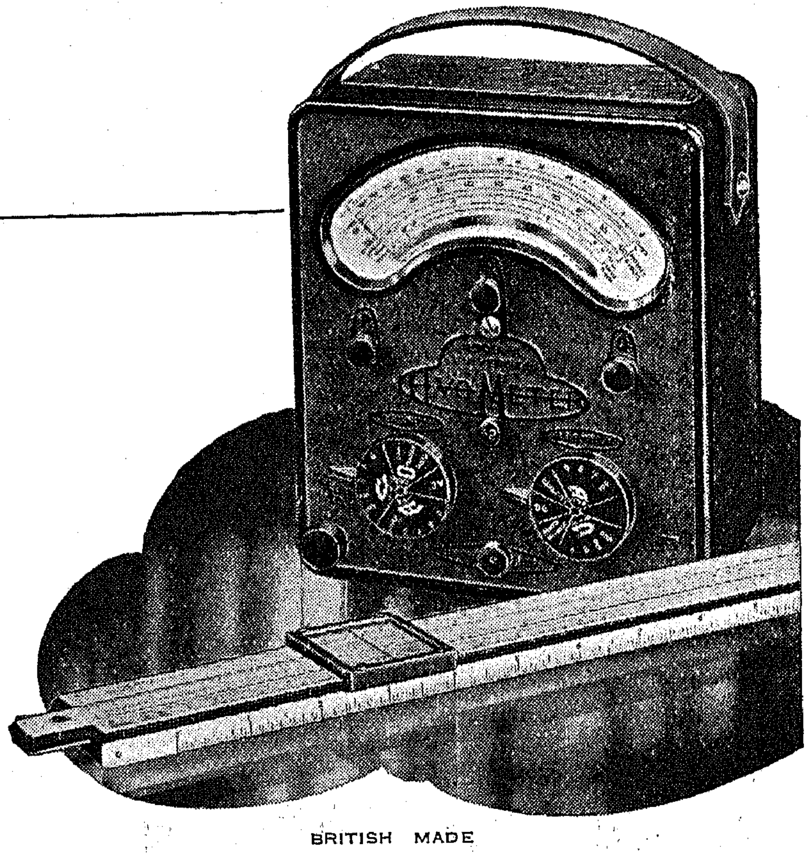
TELEPHONE
BLACKFRIARS
8701 (8 lines)

FREDERICK SMITH & COMPANY
(INCORPORATED IN THE LONDON ELECTRIC WIRE COMPANY AND SMITHS, LIMITED)
ANACONDA WORKS, SALFORD, 3, LANCS.

TELEGRAMS
"ANACONDA
MANCHESTER"

Indispensable

Accurate and speedy calculations demand the slide rule. The Model 7 Universal AvoMeter is equally indispensable wherever electrical apparatus is used and has to be maintained in continuous operation. Unrivalled in its comprehensive testing faciltities, it provides for every essential electrical test. It has 46 ranges, and measures A.C. and D.C. Amperes and Volts, Resistance, Capacity, Audio-Frequency Power Output and Decibels. Thus, motors, dynamos, switchgear, lighting, indeed *everything* electrical can be maintained always at maximum efficiency. Simple to use, essentially portable (it weighs only 6 lbs.), it conforms to B.S. 1st Grade accuracy requirements.



BRITISH MADE

The 46-RANGE UNIVERSAL
AVOMETER
Regd. Trade Mark
Electrical Measuring Instrument Model 7

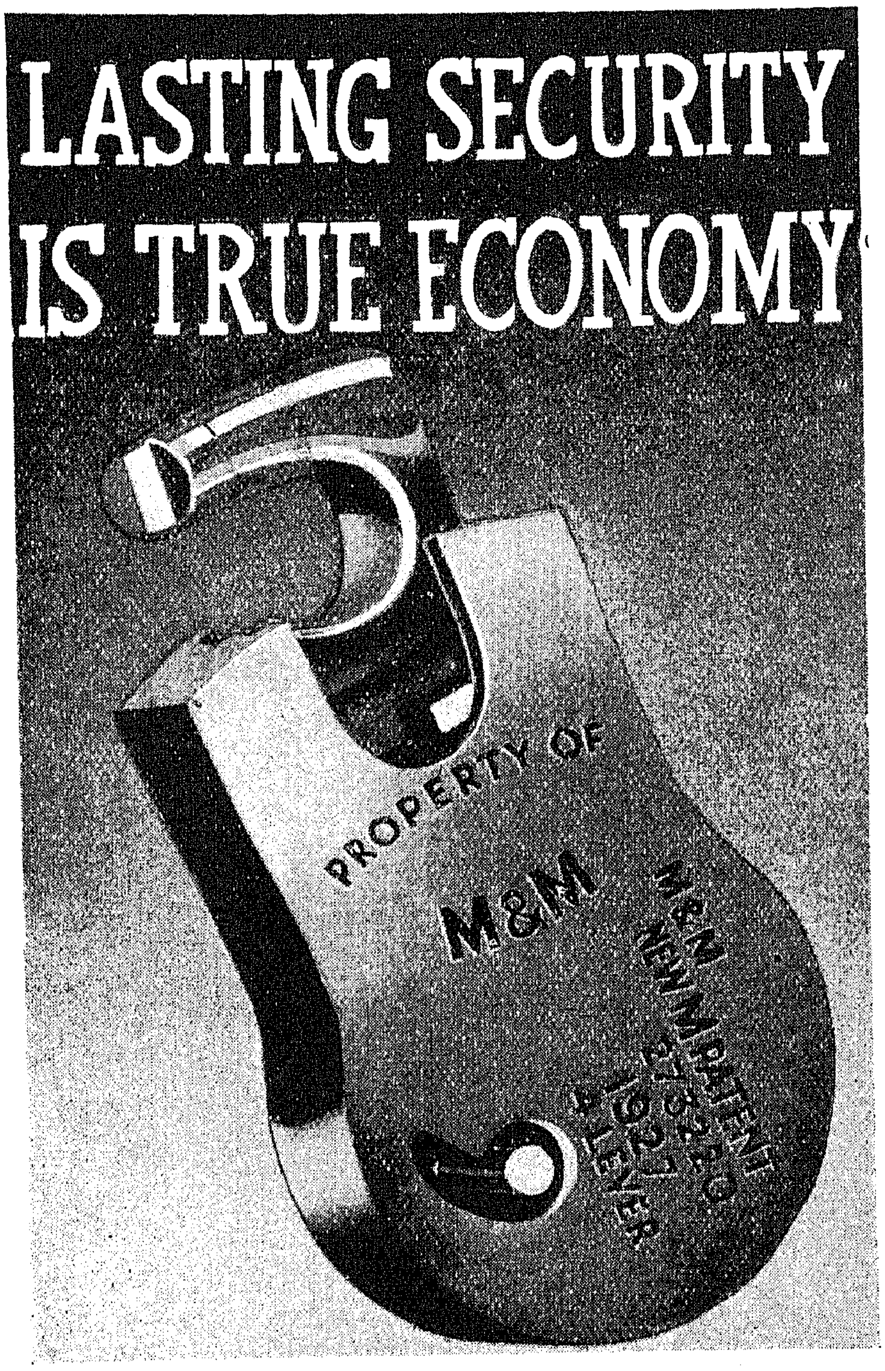
16 Gns. *Model 7 Resistance Range Extension Unit (for measurements down to 1/100th. ohm)* .. 12/6

36-range Universal AvoMeter 13 Gns.
22-range D.C. AvoMeter .. 9 Gns.
Leather Carrying Case .. 25/-

DEFERRED TERMS IF DESIRED

● *Write for fully descriptive pamphlet.*

Sole Proprietors and Manufacturers—
THE AUTOMATIC COIL WINDER & ELECTRICAL EQUIPMENT CO., LTD.,
Winder House, Douglas Street, London, S.W.1. *'Phone: VICtoria 3404-7*


LASTING SECURITY IS TRUE ECONOMY
PROPERTY OF
M&M
M&M NEW PATENT 373280 1927 4 LEVER

The saying "It's cheaper to buy the best" is really applicable to "M & M" Meter Locks. We have succeeded in producing a Meter Lock that you can confidently pin your faith to . . . it is of the lever type which is recognised as the safest type made. The "M & M" Meter Lock will resist almost any form of violence, will not rust, and will give you many years of faultless service. That's true economy! "Cheap" imitations will never give you satisfactory service, it's obvious that getting down to a price must mean vital sacrifices. Every "M & M" Meter Lock bears its registered patent number—look for it and be assured of Meter Security for as long as the meter lasts.

Write for skeletonised M & M Lock to:—

H. MITCHELL & CO.
3 & 5 LEIGHTON ROAD, LONDON, N.W.5
Phone: GULliver 2667

M & M PATENT METER LOCKS

Carew Wilson

High Quality mouldings

If it is mouldable EBONESTOS can mould it

Ebonestos have produced many of the finest mouldings manufactured in compositions, Bakelite, Urea, Diakon, and other synthetic resins. For the past 40 years, our reputation for finish and accuracy has been second to none.

Let us know your moulding requirements, and we shall be pleased to send one of our technical experts to discuss the matter with you, or, if you prefer it, meet you at our factory.

Moulders to the General Post Office, Admiralty, Air Ministry and other Government Departments.

EBONESTOS INDUSTRIES LIMITED
EXCELSIOR WORKS, ROLLINS STREET
LONDON, S.E.15 *Tel.: New Cross 1913 (6 lines)*

NOTE

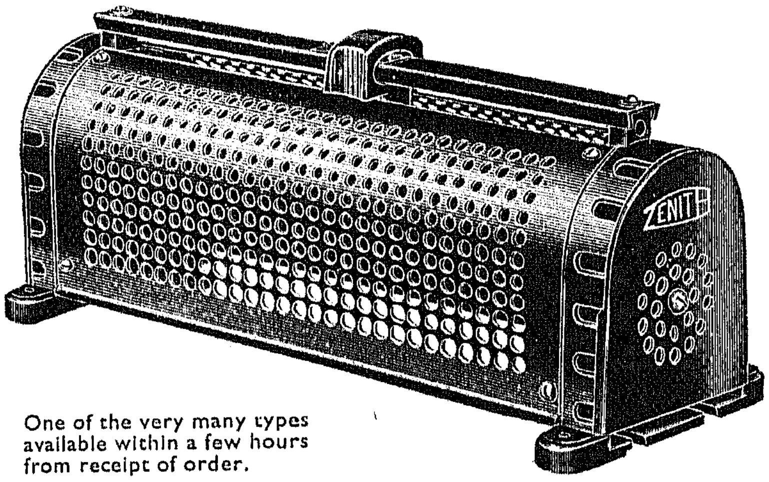
ADVERTISEMENT copy and blocks should reach the authorized agents, Industrial Publicity Service, Ltd., 4 Red Lion Court, Fleet Street, E.C. 4 (Telephone: Central 8614), not later than the 16th of each month for publication the following month.

Inquiries regarding space in this section of the Journal should be addressed to the Manager.

REGISTERED **ZENITH** TRADE-MARK

RESISTANCES

Manufactured by specialists, built for durability, and entirely British



One of the very many types available within a few hours from receipt of order.

CATALOGUE ON REQUEST

THE ZENITH ELECTRIC CO. LTD.

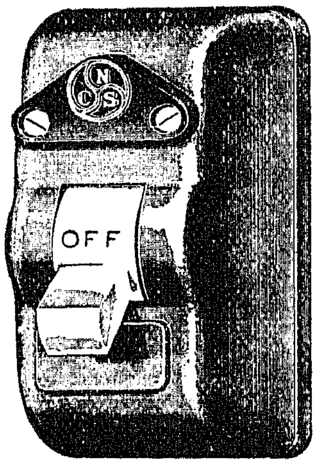
Sole Makers of the well-known "ZENITH" Electrical Products

Contractors to the Admiralty, War Office, Air Ministry, G.P.O., L.C.C., &c.

ZENITH WORKS, VILLIERS ROAD
WILLESDEN GREEN, LONDON, N.W.2

'Phone: WILlesden 4087-8-9 *'Grams:* "Voltaohm, Phone, London"

NALDERS



"BIJOU" CIRCUIT BREAKERS

For use on A.C. and D.C. circuits up to 250 volts, 20 amps.
Power type Circuit Breakers also supplied.

Ask for quotations.

NALDER BROS & THOMPSON LTD

'Phone : CLISSOLD 2365 (3 lines).
'Grams : OCCLUDE, HACK, LONDON

N C S

DALSTON LANE WORKS,
LONDON, E.8.

Keith Blackman

FANS and auxiliary equipment

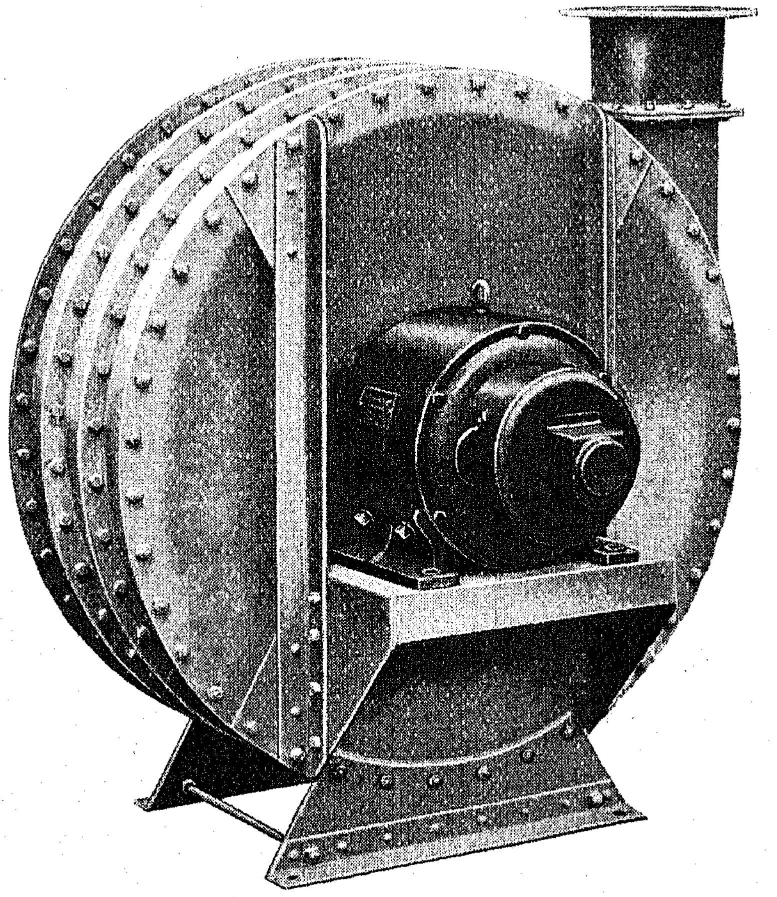
for

ventilating Buildings, Ships and Mines; providing Mechanical Draught on Boilers; blowing Forges, Furnaces and Cupolas; exhausting Metal Dust and Wood Refuse; removing Fumes, Smoke and Steam; Drying; Warming; Cooling; Refrigerating; Conveying, etc.

The fan illustrated is a "K.B." three-stage Turbo Blower, directly driven by electric motor.

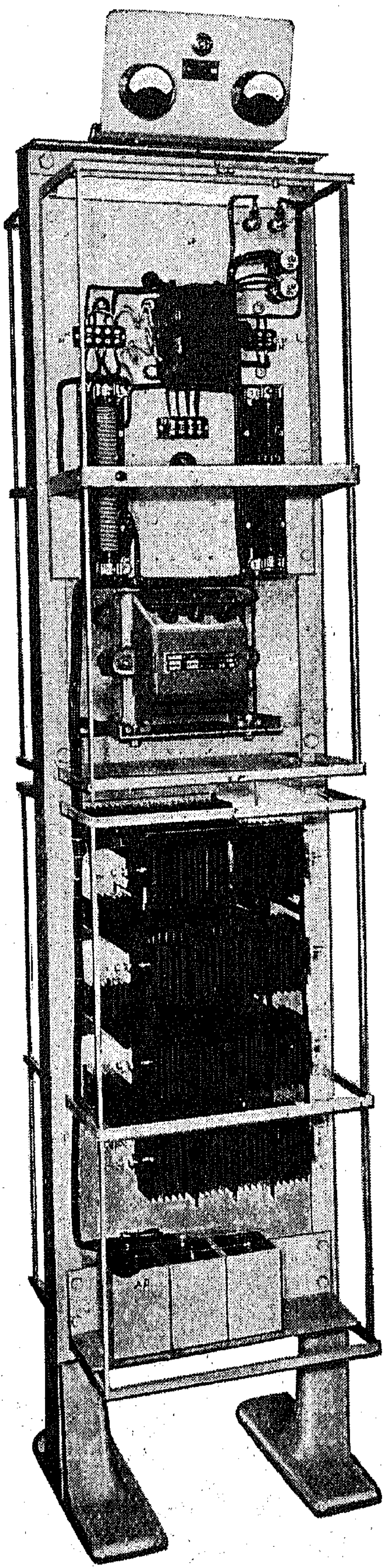
KEITH BLACKMAN LTD.

Head Office and London Works:
MILL MEAD ROAD, FERRY LANE, TOTTENHAM, N.17.
'Phone, Tottenham 4522. Grams: "Keithblac, Phone, London."



SIEMENS
"TRANSRECTER"
(Regd. Trade Mark)
AUTOMATIC CHARGING UNIT

Specially suitable for use with
TELEPHONE EXCHANGE SYSTEMS



"Transrecter" Automatic Charging Unit (incorporating Westinghouse Metal Rectifier), with cover removed.
Output 50-volts, 8 amps.

A "TRANSRECTER" Automatic Charging Unit, in conjunction with a suitable accumulator battery, provides the most efficient and reliable method of obtaining a D.C. SUPPLY FROM A.C. SUPPLY MAINS.

Current is supplied as required to meet the load conditions; the battery is automatically recharged at the proper rate to maintain it in its highest state of efficiency, and is always ready should the supply mains fail.

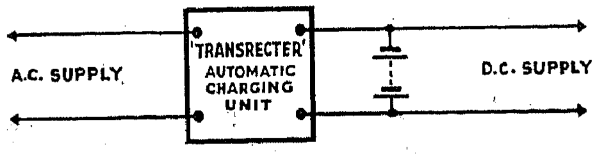


Diagram of connections

FEATURES:

- *ELIMINATES NEED FOR SKILLED MAINTENANCE & ENSURES MAXIMUM RELIABILITY AT MINIMUM COST*
- *ENTIRELY AUTOMATIC — NO RELAYS, CONTACTORS OR MOVING PARTS OF ANY KIND*
- *HIGH ELECTRICAL EFFICIENCY AT ALL LOADS*
- *ENSURES MUCH LONGER BATTERY LIFE, AND REPAIRS AND RENEWALS PRACTICALLY ELIMINATED*

Large numbers are now giving unfailing service in many parts of the world including South Africa, New Zealand, Australia, Egypt, Siam, Canada, Palestine, etc.

SIEMENS BROTHERS & CO., LTD.
WOOLWICH, LONDON, S.E.18
Telephone: Woolwich 2020

LOCAL CENTRES AND SUB-CENTRES—*Continued.*

NORTH-WESTERN CENTRE.

Chairman.—W. Fennell.
Hon. Secretary.—L. H. A. Carr, M.Sc.Tech., "Oakleigh," Cambridge Road, Hale, Altrincham, Cheshire.

SCOTTISH CENTRE.

Chairman.—W. J. Cooper.
Hon. Secretary.—R. B. Mitchell, 154, West George Street, Glasgow, C.2.
Hon. Assist. Secretary.—H. V. Henniker, 172, Craigleith Road, Edinburgh.

Dundee Sub-Centre.

Chairman.—G. F. Moore, B.Sc.
Hon. Secretary.—P. Philip, c/o Electricity Supply Dept., Dudhope Crescent Road, Dundee.

SOUTH MIDLAND CENTRE.

Chairman.—H. Faulkner, B.Sc.
Hon. Secretary.—R. H. Rawll, 65, New Street, Birmingham.

East Midland Sub-Centre.

Chairman.—T. Rowland.
Hon. Secretary.—J. F. Driver, Brighton House, Herrick Road, Loughborough.

WESTERN CENTRE.

Chairman.—H. S. Ellis.
Hon. Secretary.—G. L. Coventon, 126, London Road, Gloucester.

Devon and Cornwall Sub-Centre.

Chairman.—H. Midgley, M.Sc.
Hon. Secretary.—F. C. Isaac, Council Offices, Plympton, South Devon.

West Wales (Swansea) Sub-Centre.

Chairman.—J. E. Dawtry.
Hon. Secretary.—R. Richards, 78, Glanbrydan Avenue, Swansea.

Hampshire Sub-Centre (directly under the Council).

Chairman.—W. S. Lonsdale.
Hon. Secretary.—A. G. Hiscock, c/o City of Portsmouth Electricity Undertaking, 111, High Street, Portsmouth, Hants.

Northern Ireland Sub-Centre (directly under the Council).

Chairman.—F. Johnston.
Hon. Secretary.—J. McCandless, M.Sc., Burn Brae, Strangford Avenue, Belfast.

INFORMAL MEETINGS.

Chairman of Committee.—P. P. Wheelwright.

METER AND INSTRUMENT SECTION.

Chairman.—Captain B. S. Cohen, O.B.E.

TRANSMISSION SECTION.

Chairman.—S. R. Siviour.

WIRELESS SECTION.

Chairman.—A. J. Gill, B.Sc.(Eng.).

OVERSEAS COMMITTEES.

AUSTRALIA.

New South Wales.

Chairman.—V. L. Molloy.
Hon. Secretary.—W. J. McCallion, M.C., c/o Electrical Engineers Branch, Dept. of Public Works, Sydney.

Queensland.

Chairman and Hon. Secretary.—J. S. Just, c/o P.O. Box 1067N, G.P.O., Brisbane.

South Australia.

Chairman and Hon. Secretary.—F. W. H. Wheadon, Kelvin Building, North Terrace, Adelaide.

Victoria and Tasmania.

Chairman and Hon. Secretary.—H. R. Harper, 22–32, William Street, Melbourne.

Western Australia.

Chairman.—J. R. W. Gardam.
Hon. Secretary.—A. E. Lambert, B.E., 35, The Esplanade, South Perth.

CEYLON.

Chairman.—Major C. H. Brazel, M.C.
Hon. Secretary.—D. P. Bennett, c/o Messrs. Walker Sons & Co., Ltd., Colombo.

INDIA.

Bombay.

Chairman.—R. G. Higham.
Hon. Secretary.—A. L. Guilford, B.Sc.Tech., Electric House, Post Fort, Bombay.

Calcutta.

Chairman.—F. T. Homan.
Hon. Secretary.—D. H. P. Henderson, c/o Calcutta Electric Supply Corporation, Post Box 304, Calcutta.

Lahore.

Chairman.—V. F. Critchley.
Hon. Secretary.—J. C. Brown, c/o Associated Electrical Industries (India) Ltd., P.O. Box 146, Lahore.

Madras.

Chairman and Hon. Secretary.—E. J. B. Greenwood, Electricity Dept., P.W.D. Offices, Chepauk, Madras.

NEW ZEALAND.

Chairman.—F. T. M. Kissel, B.Sc.
Hon. Secretary.—J. McDermott, P.O. Box 749, Wellington, C.1.

SOUTH AFRICA.

Transvaal.

Chairman and Hon. Secretary.—W. Elsdon Dew, Box 4563, Johannesburg.

LOCAL HONORARY SECRETARIES ABROAD.

ARGENTINE: R. G. Parrott, Tucuman 117, Buenos Aires.
CANADA: F. A. Gaby, D.Sc., Vice-President, The British American Oil Co., Ltd., 14th Floor, Royal Bank Building, Toronto, Ontario.
CAPE, NATAL, AND RHODESIA: G. H. Swingler, City Electrical Engineer, Corporation Electricity Dept., Cape Town.
FRANCE: P. M. J. Ailleret, 20, Rue Hamelin, Paris (16e).
HOLLAND: A. E. R. Collette, Heemskerckstraat, 30, The Hague.
INDIA: K. G. Sillar, c/o Calcutta Electric Supply Corporation, Post Box 304, Calcutta.
ITALY: L. Emanueli, Via Fabio Filzi, 21, Milan.
JAPAN: I. Nakahara, No. 40, Ichigaya Tanimachi, Ushigomeku, Tokio.
NEW SOUTH WALES: V. J. F. Brain, B.E., Chief Electrical Engineer, Department of Public Works, Bridge Street, Sydney.
NEW ZEALAND: J. McDermott, P.O. Box 749, Wellington, C.1.
QUEENSLAND: J. S. Just, c/o P.O. Box 1067N, G.P.O., Brisbane.
SOUTH AUSTRALIA: F. W. H. Wheadon, Kelvin Building, North Terrace, Adelaide.
TRANSVAAL: W. Elsdon Dew, Box 4563, Johannesburg.
UNITED STATES OF AMERICA: Gano Dunn, c/o The J. G. White Engineering Corporation, 80, Broad Street, New York, N.Y.
VICTORIA AND TASMANIA: H. R. Harper, 22–32, William Street, Melbourne.
WESTERN AUSTRALIA: Prof. P. H. Fraenkel, B.E., The University of Western Australia, Crawley, Perth.

STUDENTS' SECTIONS.

LONDON.

Chairman.—P. H. Pettifor.
Hon. Secretary.—A. H. Young, "Park View," Alton Road, Roehampton, S.W.15.

NORTH-WESTERN.

Chairman.—R. Noonan.
Hon. Secretary.—R. M. A. Smith, Meter Engineering Dept., Metropolitan-Vickers Electrical Co., Ltd., Trafford Park, Manchester, 17.

SCOTTISH.

Chairman.—J. Brown.
Hon. Secretary.—G. H. Wire, c/o Mrs. Cormie, 8, Townhead Terrace, Paisley.

NORTH-EASTERN.

Chairman.—F. M. Bruce.
Hon. Secretary.—J. A. Stanfield, 44, Shipley Avenue, Milvain, Newcastle-on-Tyne.

MERSEY AND NORTH WALES (LIVERPOOL).

Chairman.—T. E. A. Verity, B.Sc.Tech.
Hon. Secretary.—W. H. Penley, B.Eng., Laboratories of Applied Electricity, The University, Liverpool, 3

SOUTH MIDLAND.

Chairman.—J. E. Woollaston.
Hon. Secretary.—B. S. Copson, 88, Reservoir Road, Olton, Birmingham.

NORTH MIDLAND.

Chairman.—A. H. Marsh.
Hon. Secretary.—G. H. Warne, 6, Parkfield Road, Shipley, Yorkshire.

SHEFFIELD.

Chairman.—
Hon. Secretary.—C. C. Bacon, Corporation Electricity Department, Commercial Street, Sheffield, 1.

BRISTOL.

Chairman.—W. H. Small.
Hon. Secretary.—J. W. Dorrington, 45, Trelawney Road, Cotham, Bristol, 6.

THE I.E.E. BENEVOLENT FUND.

The object of the I.E.E. Benevolent Fund is to help those members of The Institution and their dependants who have suffered a set-back through ill-health, or who are passing through times of stress.

HOW TO HELP THE FUND

1. Annual Subscriptions.
2. Donations.
3. Legacies.

Though your gift be small, please do not hesitate to send it.

Subscriptions and Donations should be addressed to

THE HONORARY SECRETARY, THE BENEVOLENT FUND,
THE INSTITUTION OF ELECTRICAL ENGINEERS,
SAVOY PLACE, W.C.2.

⁂

LOCAL HON. TREASURERS OF THE FUND.

Irish Centre: T. J. Monaghan. *North-Eastern Centre:* N. Cresswell. *North Midland Centre.* R. M. Longman. *Sheffield Sub-Centre:* W. E. Burnand. *North-Western Centre:* T. E. Herbert. *Mersey and North Wales (Liverpool) Centre:* A. C. Livesey. *Scottish Centre:* (*Glasgow*) A. Lindsay; (*Edinburgh*) D. S. Munro. *Dundee Sub-Centre:* P. Philip. *South Midland Centre:* *Western Centre:* (*Bristol*) E. P. Knill; (*Cardiff*) J. W. Elliott. *Hampshire Sub-Centre:* W. P. Conly, M.Sc.

PRINTED BY UNWIN BROTHERS LIMITED, LONDON AND WOKING